Energy and motorization: scenarios for China's 2005-2020 energy balance

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Zusammenfassung

Der in China beginnende Motorisierungsprozess führt zwangsläufig zu einer Konfrontation mit den Umwelt- und Ressourcenkonflikten, die mit der erdölbasierten Automobiltechnologie des vergangenen Jahrhunderts Hand in Hand gehen. Dadurch würde sich zum einen die gegenwärtig problematische Erdölenergiebilanz des Landes durch erhöhten CO^2-Ausstoß verschärfen. Zum anderen würde der Aufbau einer chinesischen automobilen Infrastruktur auf Erdölbasis, die Ressourcenknappheit in diesem Sektor, die globalen Umweltprobleme und die Sicherung der weltweiten Energiebilanz negativ beeinflussen.
Eine realistische Alternative für China ist ein Quantensprung auf dem Gebiet der Automobiltechnologie zu vollziehen und in Wasserstoffmotoren zu investieren. China kann mit einer Automobilwirtschaft auf der Basis einer Wasserstofftechnologie die durch Erdölverbrennung geschaffenen Umweltprobleme umgehen. Dieser Artikel untersucht das Potential Chinas zu einem solchen Quantensprung in der Automobiltechnologie. Ein wesentlicher Aspekt ist die Prüfung der Energiebilanz Chinas in den Jahren 1990-2000, die es ermöglicht den Energieverbrauch und die Produktion auf Quellenbasis internationaler Organisationen und wissenschaftlicher Arbeiten, zueinander in ein Verhältnis zu setzen. Die Energiebilanz der einzelnen Sektoren Atomkraft, Kohle, Erdöl und Erdgas wird analysiert und vergleichend werden die zukünftigen Trends prognostiziert. Für die Implementation von Wasserstofftechnologie ist die Verfügbarkeit und Nutzung von Energieressourcen von zentraler Bedeutung. Eine Analyse der Energiebilanz ist daher die Grundlage für eine wissenschaftlich fundierte Einschätzung des Potentials Chinas zu einem solchen technologischen Quantensprung.

Abstract

As a country beginning its motorization process, China must confront the problems attached to an oil-based car society. In adopting the conventional automobile technology, the country would aggravate an already unstable, domestic oil balance while pushing up increasing carbon dioxide levels. Not only would domestic problems emerge, but international concerns regarding oil shortage, global pollution, and the energy security balance would also result from China erecting a traditional automotive infrastructure. One viable alternative the country can consider is a leapfrog towards hydrogen technology. By using hydrogen as the fuel source and investing in a hydrogen-based car society, China could overstep the problems created by an oil-based infrastructure. Examining China's potential for undertaking this technology leapfrog also calls for an investigation of China's energy past and future. China's energy balance and energy resources play a crucial role in determining the country's leapfrogging possibility. This paper analyzes one facet in China's energy balance by scrutinizing energy expenditures between 1990-2000. By looking at data compiled from major international and academic sources, an overview of China's past energy consumption and production activities is presented. Patterns and discrepancies in Chinese coal, oil, natural gas, and nuclear production are unveiled and the trends considered in relation to the country's energy balance. Each energy sector is analyzed separately for consumption and production trends. Because implementation of hydrogen technology is governed by energy resource availability and energy use patterns, such an energy analysis provides an appropriate background from which China's leapfrogging potential can be evaluated.

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1. Introduction

1.1 Project Description

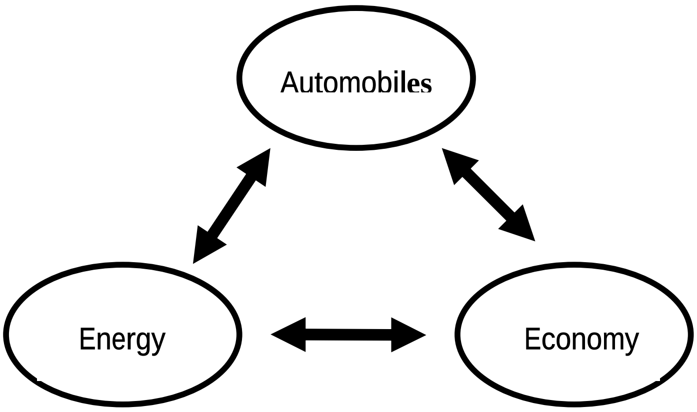
This paper, along with other specific WZB discussion papers,[1] is written under the auspices of the cooperation project "Hydrogen Technology for China's Automobile Leapfrog." The paper also connects to a previously published discussion paper exploring China's past energy expenditures, offering present and future perspectives to China's energy balance.

1.2 Study Overview

China's future development is often coupled with the notion of economic growth and technology improvements, but the country's financial and technological growth is not self-contained. External factors also shape the process of realizing economic and financial success. Technology advances and financial growth are, in part, products of industrial success. In order to increase industry production and introduce technology innovations, the country must focus not only on factories and research development, but must also consider development in connection to the energy balance. China's growing economy is currently placing the most stress on the domestic energy supply and this economic growth is inevitably hinged on the country's energy supply. When energy supply development fails to keep pace with the mounting needs stemming from a growing economy, the country's economic growth would stall in the wake of an energy shortage. According to Fortune magazine, the Chinese government is not unaware of this connection between energy and economic growth, "China's leaders know that in the long run, failure to come to grips with rising energy needs will jeopardize growth" (Fortune, February 2004). In the last decade, the industry sector played a large role in defining China's energy balance, with the transportation sector slowly emerging as another pressure point against China's energy supply. As car prices fall and ownership interest rises, the transportation sector will figure more centrally into China's energy development. Already, private car sales in the country's largest cities have grown by 55% last year, so in the next 10 to 15 years, road transport will serve as the "single most important factor driving China's increasing demand for oil" (Fortune, February 2004 & Andrews-Speed, Liao, and Danreuther 2002). China's energy balance, especially the country's oil expenditures, will be heavily affected by China's automotive development. Not only are foreign automakers conscious of the expanding private car market, but global businesses, such as the American food chain, Kentucky Fried Chicken (KFC), also forecasts China's debut as an automobile nation through its marketing strategies. Last year, the fast food chain opened the country's first drive-through restaurant in Beijing (New York Times November 24, 2003). The drive-through restaurant can be viewed as a symbol of a car-oriented nation since such a structure is only feasible in a car-oriented environment. So, KFC's decision

[1] The following discussion papers have been written for project purposes:
1. Zhu (2003): Leapfrogging into Hydrogen Technology: China's 1990- 2000 Energy Balance
2. Brie, Pietzcker (2004): NGOs in China – Die Entwicklung des Dritten Sektors
3. Weider, Metzner, Rammler (2004): Das Brennstoffzellen-Rennen. Aktivitäten und Strategien bezüglich Wasserstoff und Brennstoffzelle in der Automobilindustrie
4. Weider (2004): China – Automobilmarkt der Zukunft? Wie nachhaltig und zukunftsorientiert sind die Strategien der internationalen Automobilindustrie in China?
The above listed papers are written as part of the project exploring hydrogen options in China's advancing motorization, which is financed by project partner the BMW Group.

to introduce a car influence into China's eating culture signals the possible integration of the automobile in the daily lives of Chinese citizens. More importantly, the opening of drive-through restaurants in China hints at the speed in which China's culture will be developed. By building such restaurants now, China's automobile society can not be so far off. The Chinese government also hints at expectations for wider car ownership via its city-planning strategies. Shanghai intends to decentralize the city by moving housing and industry away from the city center. Such an intention is suggested by the city's heavy investments in rail and road infrastructure (Zhou and Sperling 2001). By placing priority on road construction and suburbia-oriented housing, the city anticipates an increase in commuter-based traffic, thereby also suggesting expansion in the city's car culture.



While the country considers structural details, such as road construction, in the context of establishing an automotive infrastructure, China's emergence as a car-based country cannot only be considered in terms of economics or infrastructure. Other effects, mainly the country's energy balance, must also be accounted for. The relationship between energy, economy, and technology advancement is inevitably intertwined. Although the Chinese government has made efforts to minimize the link between economic growth and energy consumption in the form of falling energy intensities, the connection between energy use and China's growing economy remains nonetheless in tact. Jean-Marie Bourdaire, on behalf of the IEA 2050 energy forecast, listed three stable, worldwide energy demand trends: electricity use and fuel input for power generation; fossil fuels for transport; and fossil fuels for heating buildings and industrial processes (1999). In conjunction with these energy trends, Bourdaire mentions that "fuels used for these three services have closely followed the track of economic activity" (1999). While the degree to which energy and economy is connected has been a point of debate among energy experts,[2] China's current condition reveals a symbiosis between energy and economy. Beyond the energy/economy link, technology improvements, particularly automotive technology, play a role in energy consumption and economic growth. In this light, a complex, triangular correlation between energy, economy, and a growing car society exists. Because "technology is the key determinant of economic

[2] Wankeun Oh and Kihoon Lee in their article for Energy Economics indicate: "Even though the relationship between energy consumption and economic growth has been the subject of intense research over the past three decades, the empirical evidence is ambiguous." John Asafu-Adaye also acknowledges problems in determining a consistent pattern between energy and economy. Asafu-Adaye, though attributes this to the differences in methodological approaches taken to measure the energy/economy relationship.

development and is essential for raising standards of living…,” the development of an automotive infrastructure reflects the growth of an economy fueled by energy resources (OECD 1999). But the relationship between technology advancement and economic expansion is not one sided, since a country’s economic state is one mechanism fueling or depressing technology improvements. Economic growth also stimulates car ownership. A growing economy translates into more prosperous family incomes which ultimately generates customers for the car market. The relationship between the economy and technology improvement, namely in the form of the automobile is further entangled by the energy factor. As a consequence to growth in China’s transport sector, energy demand rates, especially for oil, also rise. This deepens the connection between energy, economy, and automobiles. More importantly, the availability of energy resources determines the dimensions of China’s automotive infrastructure, a consequence influencing the number and type of cars present in the country, thereby directing economic progress.

Were every Chinese family to possess a car, the country would inevitably drain its oil supply and create added pressure on a diminishing world supply. A survey conducted in 2000 by the Association of Chinese Customers found that three out of five urban Chinese families plan to buy a car in the next five years. While this figure is not yet comparable to the one car for every family notion, the survey results nonetheless emphasize the importance Chinese families, and by default the Chinese population, place on private car ownership (www.china.org.cn). Chen Hong, general manger of Shanghai GM estimates that in the next decade, 100 million families will own an automobile (Bike Biz September 22, 2004). Were such a figure to manifest into reality, the strain on an already sluggish oil production capacity would certainly perpetuate more oil imports. Already, China’s oil reserves cannot fulfill the oil demands of a country supporting such a large population. Since 1993, China has relied on imported oil. For instance, in 2001, one-third of China’s oil demand was filled by foreign oil (Wu 2003). Reliance on external oil supplies will grow if China undertakes a full-scale motorization process. While the country’s oil fields produced sizeable amounts of oil in the past, oil supplies in these mature fields are diminishing. Unless substantial oil fields are discovered, a gasoline powered, automotive infrastructure would inexorably exhaust the country’s oil supply, making China an entirely oil importing country. Such a position would financially deplete the country and heighten China’s political vulnerability to oil rich countries. The country’s incapacity to sustain itself also damages political security, resulting in weaker political decision-making power. On an international level, China’s massive oil imports would drain an already shrinking fossil fuel supply, enhancing international tensions caused by the energy crisis. Since the mid 1990’s China has placed a priority on addressing the economic and political risks linked to heavy reliance on foreign oil and gas supplies (Andrews-Speed, Liao, and Danreuther 2002). This is suggested by the country’s aggressive search for international oil and gas sources. This year, China pulled ahead of Japan to be ranked as the world’s second largest oil importer. The country’s need for energy resources, especially oil and natural gas can be reflected by increased diplomatic and investor presence in the Middle East, Australia, and even in countries stymied by U.S. sanctions such as Sudan and Angola (Newsweek May 3, 2004). While the Chinese government makes efforts to maximize domestic energy output and diversify foreign import sources, another means to preserving political stability and equalizing the country’s oil and gas imbalance would be to adopt energy-efficient technology. This strategy suitably fits into the development of Chinese automobile technology. Since the automotive sector is forecasted to place the heaviest burden on China’s oil balance, adopting alternative, leapfrogging technology in the automobile sector may be one option that releases pressure from the country's over-taxed energy balance.

Whether exploring China's potential for establishing leapfrog technology or considering a conventional route, the energy factor must be taken into consideration. Energy data from the last decade show a heavy dependence on coal and a reduction in oil supply.[3] In the past ten years, China reduced its coal reliance by promoting and using energy-efficient technology or by substituting coal with oil, natural gas, or nuclear energy. Yet, coal continues to remain a main source in the energy balance. Oil demand and production grew from 1990 to 2000, but domestic consumption was fulfilled through external supplements. An examination of past energy patterns is only one part of the energy question since understanding China's future energy balance is a necessary component of the framework used to evaluate the country's potential for supporting a hydrogen-centric car culture. So, this paper looks at China's future energy expenditures from 2005-2020. The next two decades are crucial years for China's automobile infrastructure. As in all leapfrogging strategies, the "window of opportunity" to adopt innovative technology is limited. Already, China is shifting economic and structural gears, anticipating an increase in private-car ownership. The country's automotive sector will heavily define China's energy balance, so it is reasonable, when looking at the feasibility of a leapfrog technology, to also look at possible energy conditions against which this technology can be developed.

2. Methodology

The paper analyzes China's energy scenarios from 2005 to 2020. Future coal, oil, natural gas, and nuclear production and consumption data serve as the central sectors for analysis. Using scenarios gathered from government, academic, and international sources, an overview to China's future energy expenditures is presented. Forecasted data for production and consumption from each energy sector are separately compared for trends or discrepancies. Scenario structure and predictions concerning energy policy or structure developments are described and connected to the energy data. While this paper does not identify the most relevant or accurate scenario describing China's energy development, it will provide an overview to the future by examining existing patterns and differences between the scenarios. Such an overview can be provided by raising questions about how scenarios differ in data predictions and by considering different approaches to scenario building.

This paper bridges the past energy trends discussed in the discussion paper entitled: "Leapfrogging into Hydrogen Technology: China's 1990- 2000 Energy Balance," with possible future outcomes in the energy balance. The question of whether energy patterns from the last decade carry into the future can be considered by looking at past trends together with forecasted patterns. For logistical reasons, the year 2000 is chosen as the connecting point, since the data from the previous paper ends in 2000. When possible, charts detailing energy activities for the next two decades begin with data from the year 2000. In this way, a link is built so that past, current, and future data can be examined. Because some, but not all scenario studies (1999 is another well used reference year) use 2000 as the base year against which future energy data is

3 See WZB Discussion Paper: Zhu (2003): Leapfrogging into Hydrogen Technology: China's 1990- 2000 Energy Balance.

modeled, using 2000 as the start year proves to be entirely possible. For logistical reasons, 2000 is chosen as the connecting point since data in this paper are presented in five year increments, beginning in 2005 and ending in 2020. In order to preserve this time pattern, all charts in the data analysis section will begin with 2000 data. As previously mentioned, not all studies use 2000 data for energy modeling and therefore, not all sources provide data from 2000. For this paper, 2000 energy data is taken from all scenario studies using 2000 as reference year. Although such an approach excludes data from other base years, it is sufficient that a link between past and future energy patterns is developed as enough scenario studies utilize 2000 as base year. Since this paper chiefly outlines possible outcomes in China's future energy balance, forecasted data are the primary focus. From this perspective, numerical figures from 2005 – 2020 are documented in the appendix, while data from 2000 to 2020 are displayed in chart form.

2.2 Methodological Structure

While the energy question is mainly considered from a quantitative angle, the methodology used for scenario building as well as the models predicting changes in policy or infrastructure are also presented. Structurally, this paper is modeled along the text written by Jonathan E. Sinton and Jean Y. Ku, entitled, "Energy and Carbon Scenarios for China: A Review of Previous Studies and Issues for Future Work." But the perspective against which scenarios are considered and the intent for which this paper is written ultimately diverges from work completed by Sinton and Yu. For Sinton and Yu, the scenario reviews serve as background for which a new scenario development project has been initiated. So the scenario review is used to consider benefits and problems of various scenario building approaches and by doing so, the authors can identify research elements relevant to the new scenario building project. Instead of using the already-developed scenarios as a springboard for scenario construction, this paper is intended to serve as an overview to China's future energy trends. The energy forecasts are not analyzed for scenario development purposes, rather, the forecasts are scrutinized for future energy trends. In this case, emphasis is placed on data analysis and the possible variations on China's future energy balance. This paper acts as one of many structural elements used to develop scenarios examining the feasibility of a hydrogen-based automotive infrastructure in China. In this light, energy data functions as this paper's most integral element.

2.3 Sources

This glance into China's energy future is specifically taken from a set of non-Chinese, lenses. A collection of international forecasts serves as a relevant comparison point for examining domestic, Chinese scenarios. And due to the questionable nature of Chinese data, international statistics are also needed as a supplement or balance to domestic numbers. A February 2004 article in Fortune magazine pointed to the problematic energy sector forecasts developed by city planners, especially in the power generation sector: "…planners have consistently misjudged demand, forecasting a 5% rise in electricity usage last year when actual growth jumped 15%." From this perspective, international sources may serve as an effective counterpoint to Chinese data sources. Due to differences in methodological practices and more rigid energy calculation guidelines, international predictions of China's future energy balance may significantly differ from domestic forecasts. In this case, the relevancy of domestic data may be called into question, compelling a re-interpretation of Chinese-based figures. For instance, Thomas G. Rawski uses international data sources as a means to examine the reliability of Chinese GDP statistics. By comparing international data with domestic data, Rawski shows the implausibility of Chinese growth estimates. International energy forecasts can serve a similar purpose when domestic energy predictions are analyzed. Non-Chinese predictions can be used to verify or to disprove domestic energy projections. Jonathan E. Sinton and David G. Fridley successfully argue that China's energy statistics remain important data sources: "official statistics are not necessarily always accurate; of course, they are an irreplaceable starting point for analyzing a national energy system" (2003). But in the process of acknowledging the place Chinese data holds for our understanding of the country's energy balance, Sinton and Fridley also point out the need for caution when interpreting Chinese statistics: "For some analytical purposes, the public sources are insufficient, and some commercial information providers exist that can fill in some of the gaps" (2001). Cross-checking Chinese data with other indicators is one means through which international statistics are utilized for analytical purposes. Sinton and Fridley do not refer to forecasted energy data when discussing Chinese energy statistics, but it can be justly assumed that the same degree of prudence and same considerations for validity must be exercised when considering Chinese energy forecasts. Although most international sources use official Chinese data to generate their energy figures, the modeling systems designed by non-Chinese studies are, in general, clearer and more accurate than the methodology adopted by domestic studies. Analysts using Chinese data must also take false or inconsistent data reporting into consideration when using Chinese sources. From these standpoints, international data sources serve as an appropriate counter-balance, since data generated by international sources make adjustments for inaccuracy or inconsistency of the Chinese data. Data collection is a main component of quantitative analysis. Traditional data collecting strategies such as through academic publications found in book and journal form were taken, but data sources from non-academic organizations such as international yearbooks were also accessed. Many organizations and academic sources publish statistical data in print form and as electronic databases, so the internet and digital data in CD-ROM form also served as important data collecting points. While sound methodology is crucial for data reliability, not all the scenarios presented in this paper offer precise methodological descriptions. A few of the energy forecasts presented in this paper were used as a vehicle through which other issues were discussed. So the energy scenarios in these studies were not end products themselves, but rather a means to an end. In such cases, the authors placed less emphasis on describing the methodology for energy forecasts since the energy data are not the main focal point. This does not mean that the energy data lack a clear methodological basis, it suggests instead, that forecasted energy data were used to substantiate another point. These energy forecasts are nonetheless included in this paper. Because this paper seeks to present an international overview to China's energy future, it is essential that many perspectives towards energy expenditures are incorporated here, especially since an overview functions as a broad and comprehensive survey. All prominent international forecasts are conducted along clear, scientifically-based methodologies, but data from these sources usually fall into similar production and consumption patterns. Despite the difference in methodological approaches taken by these international scenario developers, such agencies often use the same sources for developing forecasted data. As a consequence, data from major international forecasts may be quite homogenous. Since this paper intends to present an overview to China's energy activities, it is necessary that the perspective towards energy consumption and production is a multi-perspective one. So, the inclusion of studies without a direct energy focus is not unacceptable as these scenarios may enhance data range. This strategy is justified since this paper intends not to determine the most viable scenario describing China's future energy expenditures, rather it attempts to present the widest possible overview. Since energy is not the primary focus of studies missing an explicit methodological section, the energy topic may be approached from a different angle, providing varying considerations to China's energy balance.

Because the paper compares data from a consecutive period in China's future, from 2005 to 2020, only sources presenting data covering the entire analysis period were included in the investigation. Although many existing sources offer single data points, these sources were excluded from this study. This paper examines potential trends or patterns in China's future energy balance. In order to effectively indicate these trends, a set of data in a single time series from the same source is required. Trends are not distinguishable from single data points, nor are they easily discovered by many single data points from separate sources. Patterns are best discerned using a complete data series from the same source since such data are developed out of the same methodological approach. Also, the very definition of an energy trend/pattern calls for consecutive data points. Because single pieces of data pulled from different modeling systems and chronologically combined into a single time series are not scientifically valid, this paper omits scenario studies projecting single data points.

2.4 Energy Sector Data

Future consumption and production patterns from four energy sectors are examined here. The data presented for each energy sector is composed of total amount of coal, oil, natural gas, and nuclear energy required and produced by all energy-reliant domestic sectors. Due to the direction of China's economic development, automotive growth will be heavily dependent on primary energy sources. Although renewable energies also help shape China's energy landscape, the country's reliance on these sources accounts for a negligible share of the energy balance. The Chinese government intends to increase renewable energy consumption by 17% in 2015 (*Die Zeit* June 9. 2004). In spite of efforts to raise alternative energy consumption in the long term, the assigned role of renewable energy in the energy balance will remain comparatively minor. Also, considering the rate at which renewable energy is currently implemented into the energy balance, 17% renewable energy consumption by 2015 is an incredibly optimistic prediction. As a consequence, at least for the next two decades, renewable energy availability will not significantly affect the extent to and by what means the economy, and therefore mobility, develops. Since few scenarios have extensively forecasted renewable energies use in China, few consecutive data sets exist for pattern comparison. Most available data over renewable energy data exist in the form of single data points, which are not included in this study. The future of renewable energy utilization and growth cannot be overlooked, as these energies are means to hydrogen production. In terms of appraising possible energy conditions for the next two decades, it is important to first examine resources which serve as catalysts to larger conditions such as economic change, and for purposes of this paper, automotive development. From this light, primary energies such as coal, oil, natural gas, and nuclear energy are key players in the energy mix and will dominate China's energy balance, so it is relevant that the focus on this paper is directed toward these four main energy sources.

Data collected for this energy comparison exclude energy figures for electricity/power generation. A few scenarios only focus on energy production and consumption and consider power generation separately. Some scenarios include power generation in production and consumption figures while simultaneously presenting separate data for primary energy expenditures and power generation. For consistency, specific energy data related to electricity/power generation is omitted from this data comparison. Because the power sector is nonetheless an energy-related sector, a glance at electricity generation is presented via graphic form. Otherwise, data included here cover primary energy production and consumption for each energy sector. While many scenarios break down energy consumption and production along sector-specific lines, this is not an approach taken by all scenario developers. To effectively compare energy data, a common basis through which the data can be examined is required, so energy data must be presented in the broadest scale possible. Details related to energy usage by domestic sectors such as industry or transportation are nevertheless crucial for understanding the future energy balance, so energy expenditure trends by domestic sectors are separately described under the scenario review.

2.5 Unit Conversion for Data

The data compilation and organization process is also essential to data analysis. To effectively compare data, all related, statistical collections must share the same unit of measurement. Therefore, all data were converted into a single, scientifically acceptable unit. The metric system was used in the conversion process due to the system's prominence in the scientific community.[4] Data were converted into the common metric measurement for each specific sector. Because most scenario studies measure energy in Metric Tonnes of Oil Equivalent (Mtoe), converting data into a common unit served only as a small barrier. Conversion accuracy was ensured by using online metric conversion systems and then manually crosschecked by using the International System of Units conversion equivalents. While most data are measured into convertible units, not all data shared this quality. Occasionally data from the same sector were measured in different units such as mass or energy. Because energy units are not adaptable to mass equivalents, data within the same sector are occasionally separated into two sub-sections, due differences in units.[5] This divergence in units does not affect data analysis, as the data analysis does not compare specific figures against each other. Instead, energy patterns were examined and trends from separate units are comparable. All data were converted to three significant figures, allowing clear data analysis while eliminating the complications connected to numbers exceeding three significant figures. Data were structurally and numerically presented in graphic and chart form. All data sharing the same unit and falling into the same sector were plotted on one graph as well as organized in the same data chart. Another factor to be considered in data compilation concerns data structure. While some organizations forecast future energy expenditures by making one numerical estimate for every five year increment, some scenarios present a data range for every five year increment. Because a data range can not be plotted on a

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[4] The following conversions were used in this study:
1 million short ton: 0.9071847 mt
1 mtce: 0.6543 mtoe
1 mtoe: 1.33 GW
1 cubic feet: 0.02831 cubic meter

[5] Some scenarios calculated consumption and demand for each primary energy in terms of weight/mass such as in metric tonnes or short tonnes, while some studies measured data in energy units such as tonnes of oil equivalent. In the case the same energy is measured by different sources using incompatible units, separate charts are constructed to document possible trends.

column graph for comparative uses, the median point for all scenarios using a data range is used when inserting data into column charts.

2.6 Data Organization

In order to look at the trends in China's future energy expenditures, data were organized into column graphs according to specific energy sectors. Data were also separated according to production and consumption. Because the graphs are used for comparative purposes, the scale of each energy sector, depending on unit of measurement remains the same for production and consumption graphs. Since every energy sector is measured in a different unit, no general scale is available to measure all energy sectors. Instead, graphs from specific energy sectors share the same scale in production and consumption charts. This system allows for comparison between data within each energy sector, but prohibits comparison between data from two different energy sectors.

Along with diverse methodological approaches used by different scenario developers, terms describing energy consumption and production also varied. While some scenarios described energy activities in terms of future "production" and "consumption," other organizations used "supply" and "demand" when discussing the amount of energy resources available for the future.[6] In order to establish vocabulary consistency, China's energy resources will be described in terms of future energy "production" and "demand" rates. Since terms such as "production " and "demand" may contain dissimilar meanings, to avoid data misinterpretation, all studies were checked for consistency in definitions. Some scenarios lacked specific description of such general terms, but the definitions can be inferred from the scenario contents. With the exception of the scenario written by the Asia Pacific Energy Research Center (APEC Energy Demand and Supply Outlook 2002), which builds only a "reference case scenario," all studies construct not only a "business as usual" or "reference case scenario" but also build scenarios based on high/low economic development or high/low energy prices. Because different economic conditions affect energy usage, all possible energy paths are included for comparison.

One scenario: "China's Energy: A Forecast to 2015" is a descriptive scenario. No data time series data were available in the text. Nonetheless, it remains a relevant source from which to draw a picture of China's future energy activities. This scenario will not be included in this paper's data analysis section, instead, the scenario will also be considered in the section where scenario results are summarized and methodology is investigated.

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[6] Asia Pacific Energy Cooperation (APEC) Energy Demand and Supply Outlook uses "supply" and "consumption" in describing energy activities. Natural gas data from *Natural Gas in Asia: The Challenges of Growth in China, India, Japan, and Korea* uses "production," and "consumption" when describing future natural gas expenditures. Authors from the "Future Implications of China's Energy Technology Choices" use the term "production" in its scenarios. The International Energy Agency's (IEA) World Energy Outlook describes energy in terms of "supply" and "demand." The International Energy Outlook, compiled by the Energy Information Administration (EIA) uses the terms "production" and "consumption." The Center for Strategic and International Studies uses the terms "fuel use" and "production" in its scenario. The Japan Bank for International Cooperation and its scenario, "Energy Balance Simulations to 2010 for China and Japan" define energy activities as "demand" and consumption." The World Bank Discussion Paper: "China: Issues and Options in Greenhouse Gas Emissions Control" explains energy expenditures as "energy use" and "consumption."

3. Data Analysis

3.1 Introduction to Data Analysis

Against the background of the scenario review, the qualitative data developed from the collected scenarios is presented in four energy sectors: coal, oil, natural gas, and nuclear energy. Because the forecasted figures are calculated according to the methodology designed by each scenario, the modeling systems from each scenario is first outlined in the scenario review so the nature of the qualitative predictions is placed into context. This section is entirely centered on qualitative data. By grouping together forecasted data from all scenarios, any patterns, similarities, or discrepancies in energy projections can be discerned. Data analysis is divided into the above mentioned four energy sources as well as separated along supply and demand categories. Contrasts and similarities in projections will be graphically presented as well as textually analyzed. Because some sources consider more than one energy path, taking into consideration growth or drops in economic development, these sources present different scenarios for the same energy sector. In this situation, all "reference case" or "business as usual" scenarios will be compared, with high and low economic growth scenarios to be analyzed separately for trends.

The structure used in analyzing data for this paper resembles the foundation built in the discussion paper entitled, "Leapfrogging into Hydrogen Technology: China's 1990-2000 Energy Balance" (Zhu, 2003). Because this examination into the future energy balance serves as a link to the past energy balance, the means through which the data is explored must be compatible. In this way, a connection between past and future energy balances can be paved. In establishing such a link, any transformations to the energy landscape can be easily noticed. Because the country was already making efforts to redefine its energy balance in the last decade, this examination into the future is an appropriate step oncoming decades. An analysis of the future energy balance is also a comparison point to the energy balance from the last decade. Any patterns or changes in energy utilization from the past into the future can be considered in the link between the two papers. In the process of looking at future energy activities, past energy use as documented in the above-mentioned discussion paper will be considered.

3.2 Overview of Energy Balance

A general picture of energy consumption is presented in Table 2 in which total primary energy consumption is forecasted by various scenario studies. While not all sources offer an overall energy consumption forecast, Table 2 presents all scenarios used in this paper making a forecast in primary energy consumption. General consumption is measured in percentage points against the respective base case used in each scenario study. Because all scenarios are developed from different base years (see Section 3: Scenario Review), forecasted growth levels must be considered in relation to the base year against which the scenario is built. The following table presents energy consumption as forecasted for the business-as-usual case.

Energy Consumption Growth by Percentage

	World Bank	DOE	JBIC	IEA 2000	APEC	IEO 2003	EPJ (Li ZhiDong)
2000	4.1	6.0	1.5 - 2	3.2		3.8	3.6
2005	4.1	6.0	1.5 - 2	3.2	2.7	3.8	3.6
2010	4.1	6.4	1.5 - 2	3.2	2.7	3.8	3.6
2015	4.1	6.6	1.5 - 2	3.2	2.7	3.8	3.6
2020	4.1		1.5 - 2	3.2	2.7	3.8	3.6

Table 2

With the exception of DOE consumption figures, forecasted consumption rates from available scenario were consistent across the board. While most consumption rates ranged between 2 and 4%, DOE estimates energy consumption to grow beyond 6% in the next fifteen years. The biggest discrepancy in predictions measured at 5.1%, between DOE and JBIC figures. Not considering the DOE estimates, expectations for future consumption from the scenario studies remain homogeneous, with most predictions falling in the 3% range.

Because energy forecasts are made against the framework of a country's economy, any consumption increase in the next two decades must be considered in relation to China's economic growth. Table 3 shows forecasted economic growth from most of the scenario studies since not all sources used in this paper made economic forecasts. Changes in China's development are measured in percentage points. The economic landscape represented in Table 3 is built along a business-as-usual case in which China's economic transformation continues undisturbed.

Economic Development

	World Bank	JBIC	IEA 2000	JCIE	IEO 2003	EPJ (E. Larson)	EPJ (Li ZhiDong)
2000	8.0	7.0	7.0	7.4	6.2	7.0	7.9
2005	8.0	7.0	6.0	7.4	6.2	7.0	7.9
2010	8.0	7.0	6.0	7.4	6.2	5.5	7.9
2015	6.5	7.0	6.0	7.4	6.2	5.5	7.3
2020	6.5	7.0	6.0	7.4	6.2	5.5	7.3

Table 3

Economic growth, across the board, appears consistent, with all sources, making uniform predictions for China's economic development in the next decade. The greatest disparity in economic growth lay between the scenario developed by Eric Larson, et al (Energy Policy Journal) and the World Bank Scenario for the year 2010 in which a 2.5% difference separates the Larson, et al forecast from the World Bank prediction. Aside from this disparity, forecasts from the scenario studies forecast China's annual economic growth to fall between 6 and 7%.

Electricity Generation

As previously mentioned in the methodology section, energy use for the power generation sector will not be explored in detail. Instead, a brief summary is presented below.

The link between economy and energy is especially manifested between the relationship China's industries share with the power generation sector. In the past two decades, China averaged an estimated 8% annual growth of installed electricity capacity, but the current electricity supply cannot fulfill the demand spurred by residential and industrial usage (Yeoh & Rajaraman, 2004). The industrial sector, especially, depends on abundant and consistent electricity production, serving as the leading consumer of power. Because the industrial sector drives China's economy, the availability of electric power serves as the "lifeblood of an economy." In 2003, the electrical capacity in China could not meet demand, resulting in shortages, forcing abrupt factory shut-downs and leading to unfilled factory orders (People's Daily February 25, 2004). Since the country's economy rests heavily on industrial output, factory closures resulting from power shortages directly affects the country's economy. Growth in the residential sector and city planning also heightens electricity demand as power-heavy sectors such as cement, steel, and aluminum escalate production (Los Angeles Times September 4, 2004). Already, Chinese officials foresee a continued, unfulfilled gap between power supply and demand.

In general, rises in power consumption complements economic growth, but in China, electricity consumption rates have surpassed economic growth figures. A combination of inefficient energy consumption, especially in the industrial and residential sectors; ineffective energy forecasting, and a restructured generation industry affect the supply/demand ratio. In anticipation of inevitable power shortages, the Chinese government is making efforts to reduce the disparity between supply and demand. According to People's Daily, new power generators with capacity up to 420 KW's were scheduled to go online by the end of 2004 (February 25, 2004). In an effort to reduce electricity use during prime hours, electricity prices for the peak hours are set higher, compelling factories to shift production to evenings and weekends. Electricity prices in general have also been raised 4.4%, in attempt at reducing overall electricity use (BusinessWeek July, 2004). Yet, electricity consumption would decrease more quickly if energy saving measures in the industrial and residential sector were stringently applied.

When considering China's future energy balance, power generation must be included in the energy balance. Although electricity supply and demand does not directly affect China's automotive infrastructure, the country's power supply does play a role in directing the country's economic growth, which in turn influences automotive development. The following table presents forecasted electricity generation rates in Terawatt hours. As already pointed out, this glance into power generation, albeit brief, does give a general view into how power generation is analyzed for the future. Unlike energy consumption rates, forecasted figures for electricity generation are not so consistent. The range of predicted generation rates is broad and forecast disparities measure around 3000 TWh for 2010 and around 5000 TWh in 2015. Despite the wide discrepancies in the forecasts, a general pattern for power generation does emerge from the predictions. For the next two decades, electricity generation is predicted to increase annually and actual generation figures fall between 2000 and 3000 TWh.

Electricity Generation (TWh)

	World Bank	JBIC	IEA 2000	JCIE	APEC 2002	EPJ (Eric Larson)	EPJ (Li ZhiDong)
2005		~1425				~1350	2332
2010		~1584	2408	4700-5000		~2600	2332
2015				6900-7400		~2950	2332
2020	3850		3691			~3200	3772

Table 4

3.3 Coal

Coal Production

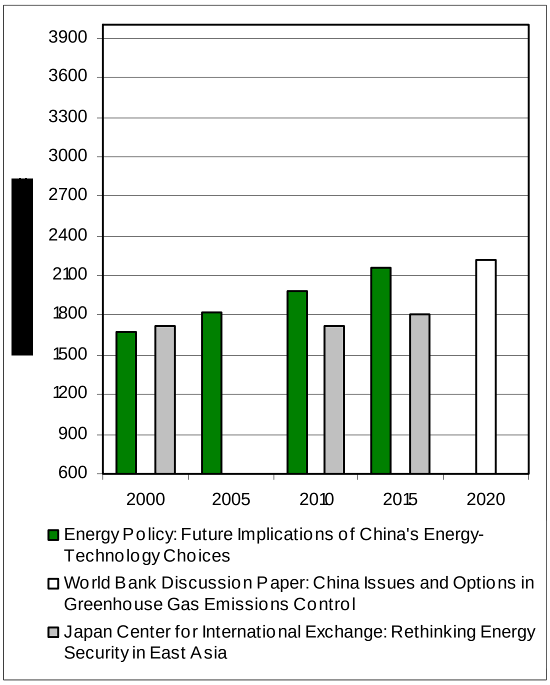

Figure 1

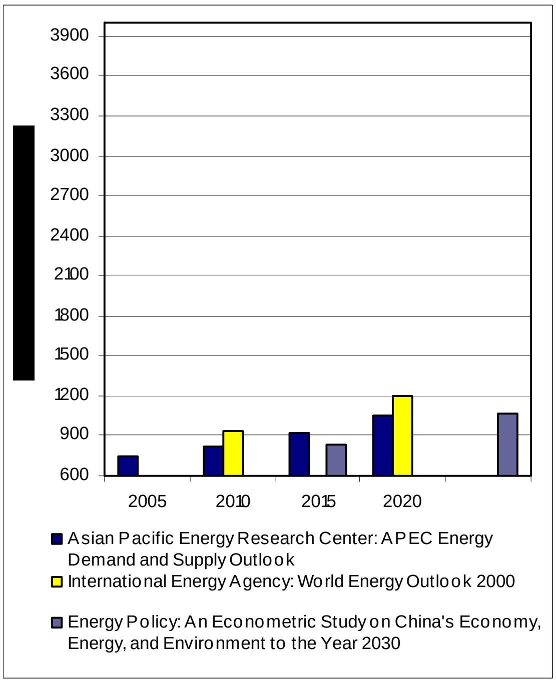

Figure 2

Coal Production: High Substitution

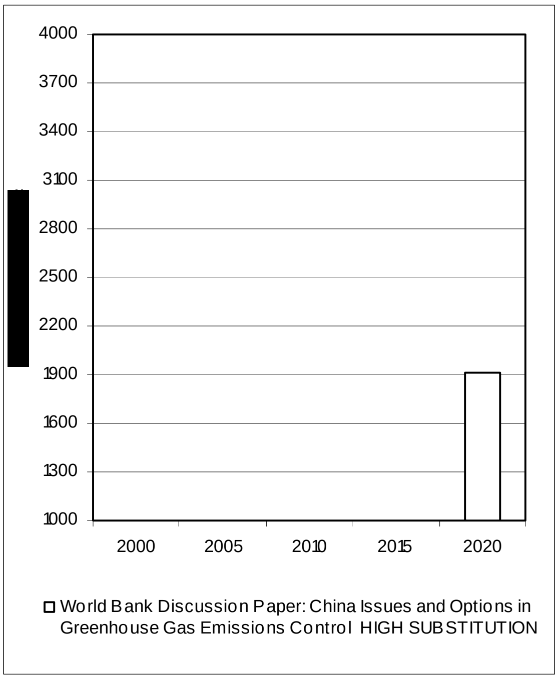

Figure 3

Coal production trends do not vary between figures 1 and 2. All sources forecast coal production to increase in the next two decades. While the difference between data is negligible in figure 1, the level of production growth is slightly more varied in figure 2. All data sources show an upward increase in coal production. Although the pattern reflects such an increase, the rate at which production occurs appears minimal from all data sources. The discrepancy between coal production data is small, ranging from 305 Mt in figure 1 to 139 and 114 Mtoe in figure 2. The World Bank Study offers two possibilities for China's coal production future. Figure 1 describes the "baseline" possibility and figure 3 considers the amount of coal produced when the maximum amount of alternative energy sources are substituted in place of fossil fuels. Despite the possibility of replacing alternative energies with fossil fuels, a reduction in the coal production rate under the high substitution scenario remains minimal. This overall pattern, in which coal production slowly, but steadily increases into the next decades appears as a continuation of the last decade's production pattern.[7] According to international sources, coal production dropped between 1990 and 2000. Yet, the production trend from the scenario sources, suggests that it will not continue along the last's decade's descending pattern. Instead, coal production is forecasted to slowly rise in the next two decades. Although most scenario studies point to a reduction of coal in the energy balance, production rates, nonetheless, continue to rise. This is especially shown in the reference case forecasts, in which all sources exhibit rising production rates.

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[7] Assumptions are based on the discussion paper by Ying Zhu entitled "Leapfrogging into Hydrogen Technology China's 1990-2000 Energy Balance."

Coal Demand

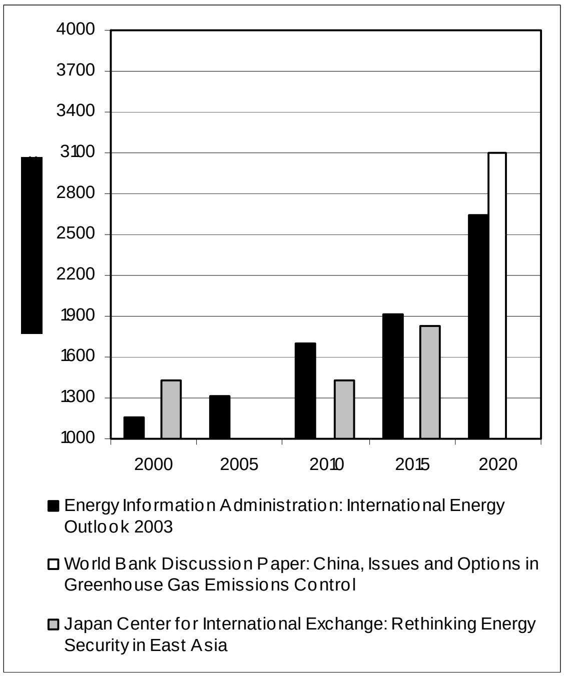

Figure 4

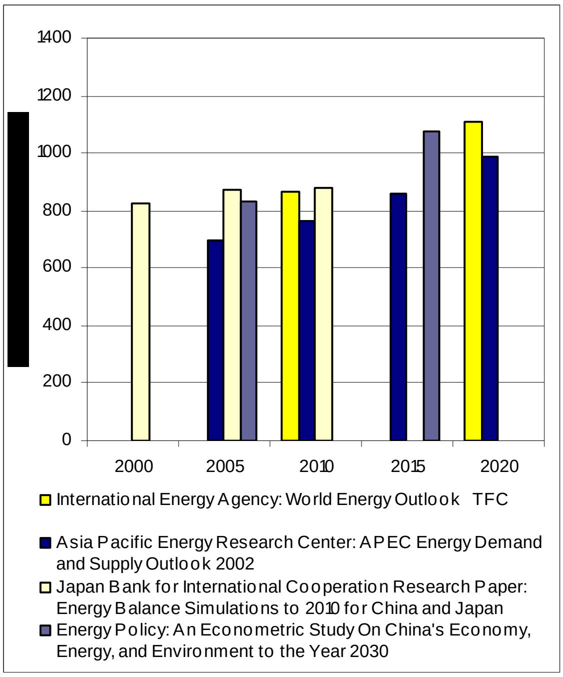

Figure 5

Coal Demand: High Economic Growth

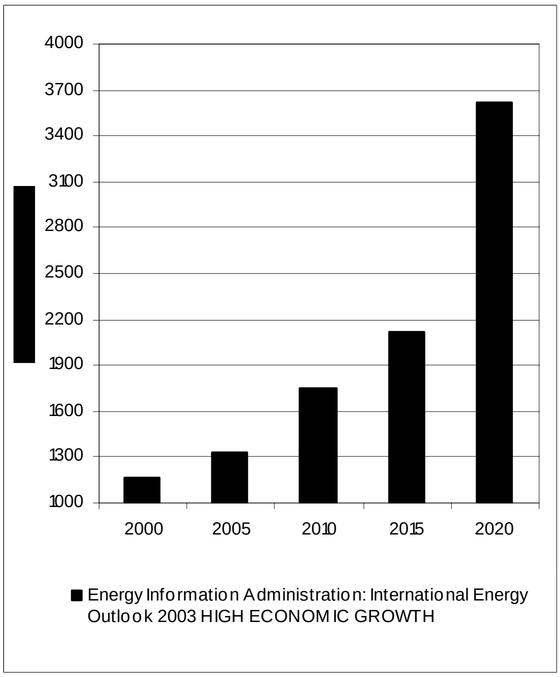

Figure 6

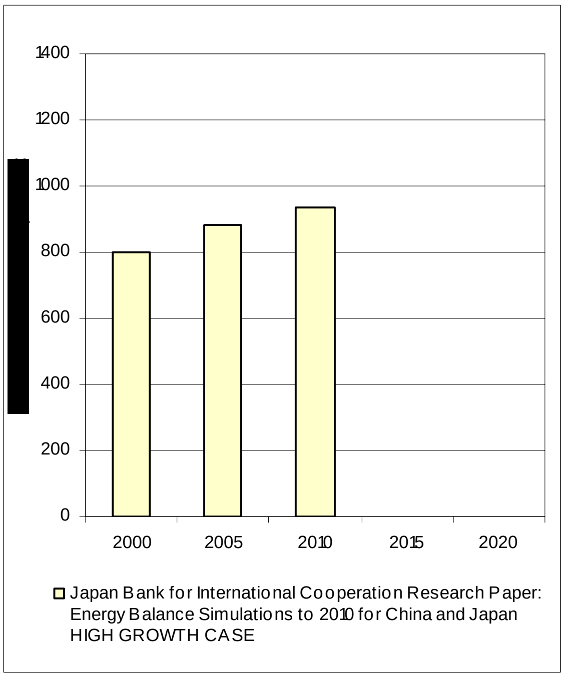

Figure 7

Coal Demand: Low Economic Growth

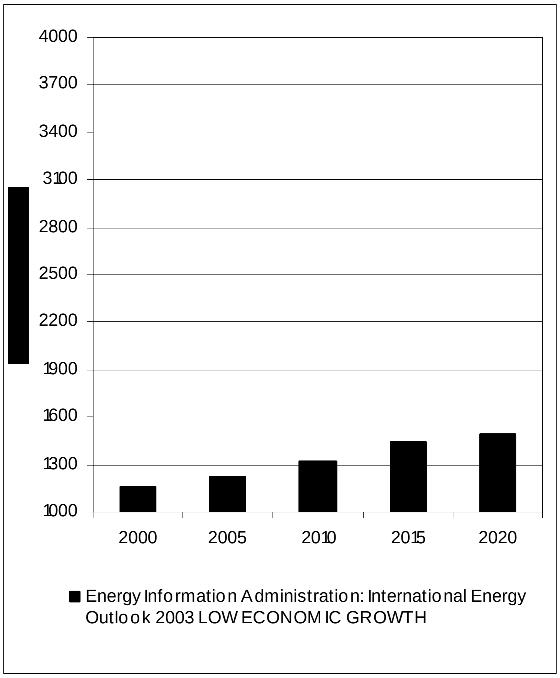

Figure 8

The trend in all figures suggests China's future coal consumption to gradually increase. All data sources from reference cases reflect the same rising consumption level. The disparity between data sources is negligible as all sources from figures 6 and 7 show slow, but increasing patterns. Both the Japan Bank for International Cooperation (JBIC) and the Energy Information Administration present energy scenarios based on "high economic growth." While both sources show a growing consumption trend for this economic condition, the two sources differ in relation to the reference case scenario. According to JBIC, high economic growth in China implies a growing consumption trend with figures falling below the reference case scenario. In other words, were China to experience rapid economic development in the next two decades, the country would consume less coal than if it maintained its current economic level. According to the data from the EIA, high economic growth is coupled with an increase in coal consumption, with figures exceeding its base case scenario. However, despite the difference in consumption rates, the trend presented by both scenario studies remains similar. Whether consumption figures are reduced or increased in a high economic growth context, the consumption trend reflects growth. Along with considering high economic insurgence, the EIA also constructed a scenario for low economic growth. On the condition that China enters two decades of low economic growth, coal consumption would continue to rise annually, but at a slower rate compared to the reference case situation. This forecasted growth continues the falling consumption pattern from the last decade. The forecast suggests that consumption for the next twenty years mirrors production tendencies, in which coal consumption will rise. This increase in consumption is not extreme, as most studies predict the amount of coal consumed in the energy balance to fall.

3.4 Oil

Oil Production

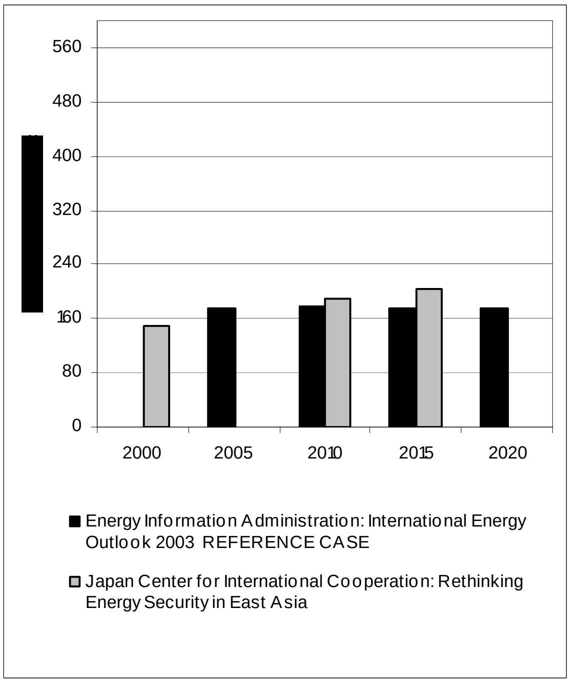

Figure 9

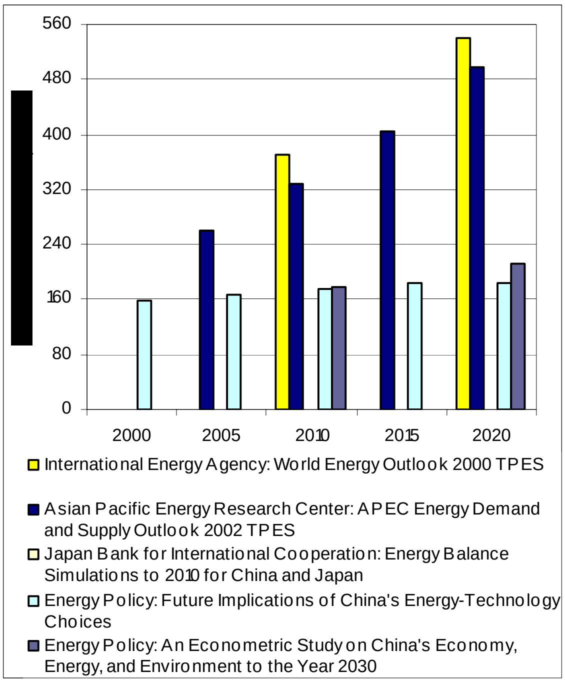

Figure 10

Oil Production: High Oil Prices

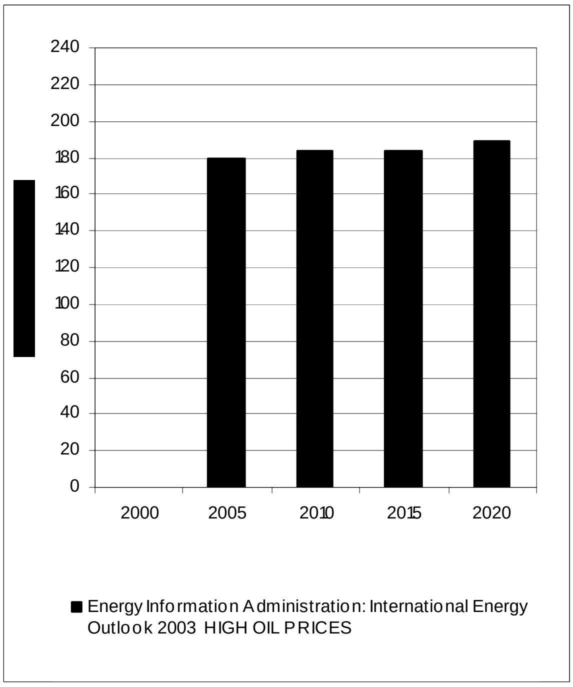

Figure 11

Oil Production: Low Oil Prices

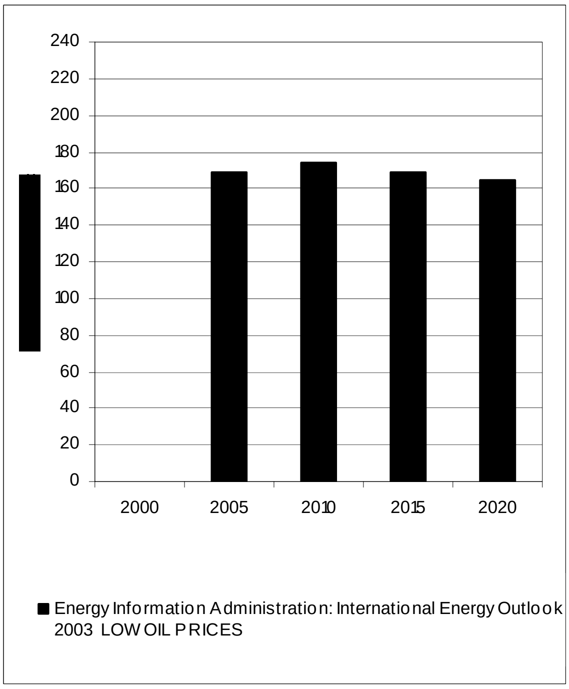

Figure 12

According to figures 9 and 10, oil production until 2015 will rise. Beyond this date, forecasts for oil production change. In figure 9, production rates drop from 2015 to 2020, while in figure 10, production rates continue increasing. Although data from figure 9 show a decrease in production, this drop is minute, but nonetheless strays from the production trend in figure 10. Data from the two sources in figure 9 display little variation, but the rate at which production rates grow in figure 10 are less consistent. The largest discrepancy between source predications is measured at 314 Mtoe for oil production in 2020 between predictions from International Energy Agency and data from Larson, Wu, Delaquil, Wenying, and Pengfei in the Energy Policy Journal. Despite the different data ranges in figure 10, the trend from all scenarios is consistent; oil production will continue to gradually rise. While sources from figure 10 show continual growth in oil production, such increases are consistently small. The EIA also projects energy developments based on the changing world prices. The EIA bases its reference case on oil prices from 2003 and suggests growth in Chinese oil production until 2015. Beyond this point, figure 11 shows a difference in production trend. The EIA scenario shows no change in trend, as oil production rises into 2020. In case the global oil market settles upon oil prices that fall below the reference case price, the EIA suggest an increase in oil production up to 2010 with drops in production rates in the next decade. Considering the link between forecasted oil production and the oil produced between 1990 and 2000, China’s future production patterns adhere to the pattern already established in the last decade, in which production will continue to rise until 2015, although the rate at which production rises is sluggish. Beyond this point, the future of 2020 production lacks a homogeneous pattern. Some scenarios forecast oil production to fall, while other sources forecast production patterns to continue upward.

Oil Demand

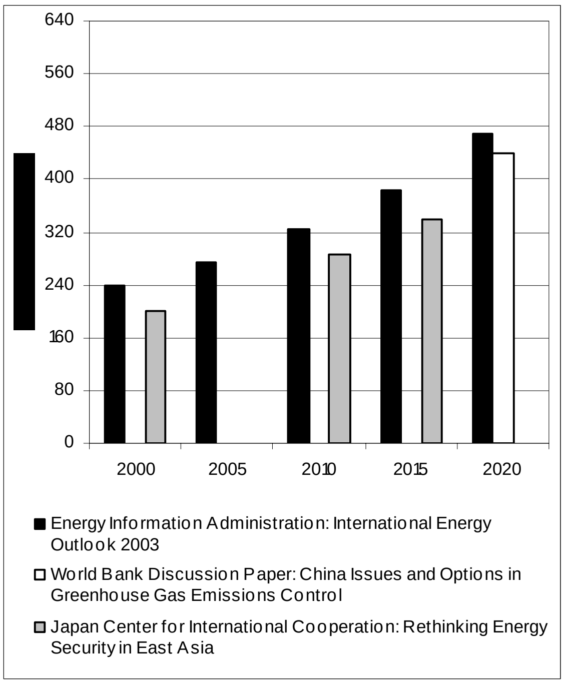

Figure 13

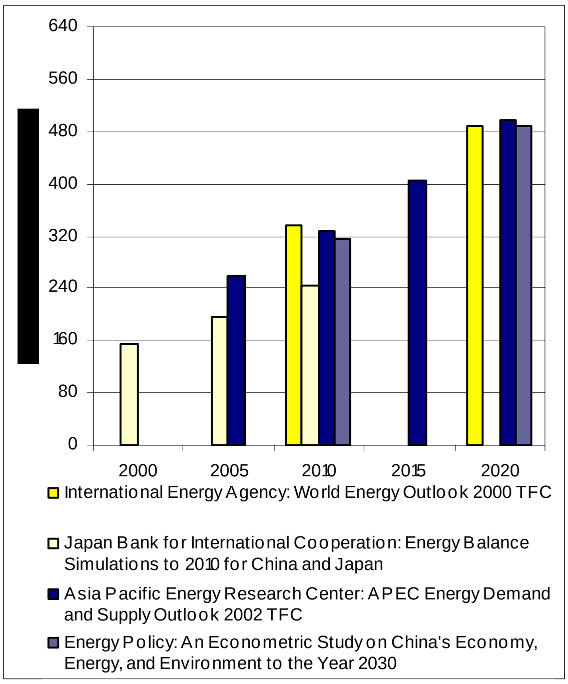

Figure 14

Oil Demand: High Growth Case

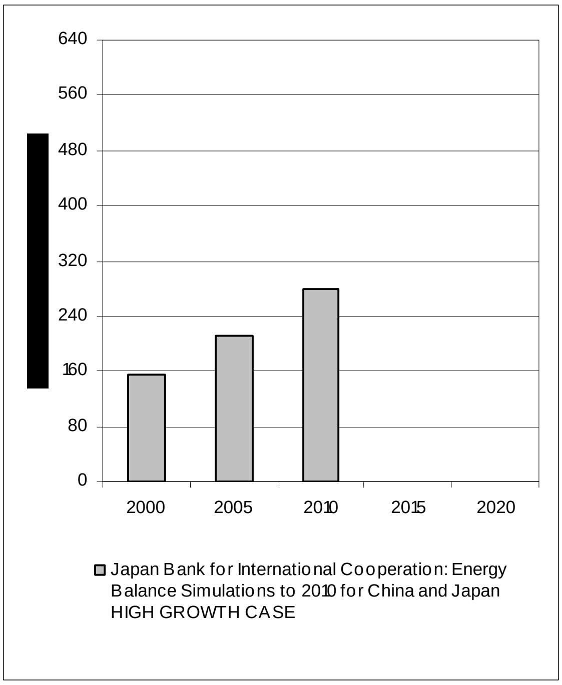

Figure 15

Unlike projections of oil production, oil consumption levels are projected by all sources to increase in the next two decades. Not only do trends in figures 13 and 14 reveal a consistently rising consumption pattern. Data dissimilarities between sources are minimal, with the greatest difference measuring at 90.4 Mtoe between the EIA and JBIC data for consumption in 2010. Figure 15 reflects JBIC's consumption scenario on a high growth case scenario in which, like the baseline case, oil demand continues to intensify. Figures from JBIC's high economic growth case unsurprisingly reflect growth levels exceeding the reference case data. Oil consumption from the last decade consistently showed demand increases and forecasted oil demand does not stray from this trend.

3.5 Natural Gas

Natural Gas Production

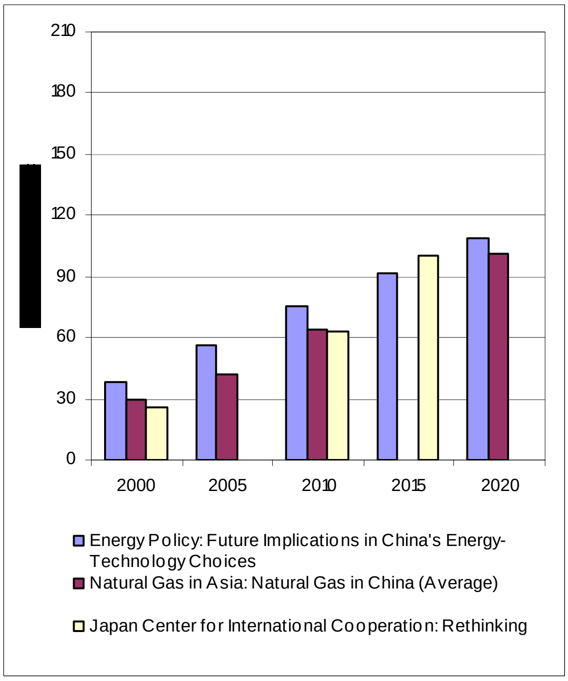

Figure 16

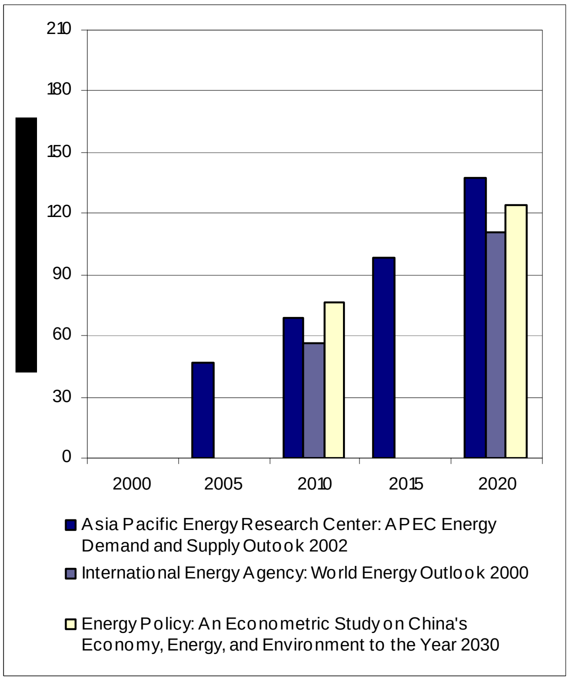

Figure 17

According to data from figures 16 and 17, natural gas production will incrementally rise in the next two decades. Although sources from figure 16 and 17 are measured in different units, the trend from figure 16 matches the rising production pattern in figure 17. The numerical difference between source data is small in figure 16, with the greatest difference of 14 Bm^3. Data discrepancies in figure 17 are only slighter larger, as APEC forecasts for production rates are consistently higher than IEA predictions, with the largest dissimilarity measured at 26.5 Mtoe. Despite variations in data, all sources predict an increase in natural gas production. Production rates will not rise very quickly, but will develop gradually between 10 and 30 Bm^3 or 15 and 35 Mtoe every five years. Natural gas production increased on an annual basis in the last decade, fulfilling the Chinese government’s ambitions to intensify reliance on the country’s gas resources. All sources from this paper project the share of natural gas in the production/supply balance to expand and the uninterrupted growth in production forecasted for the next twenty years not only follows the pre-existing production trend from 1990-2000, but also follows along administrative plans from the Chinese government to enhance the natural gas supply.

Natural Gas Demand

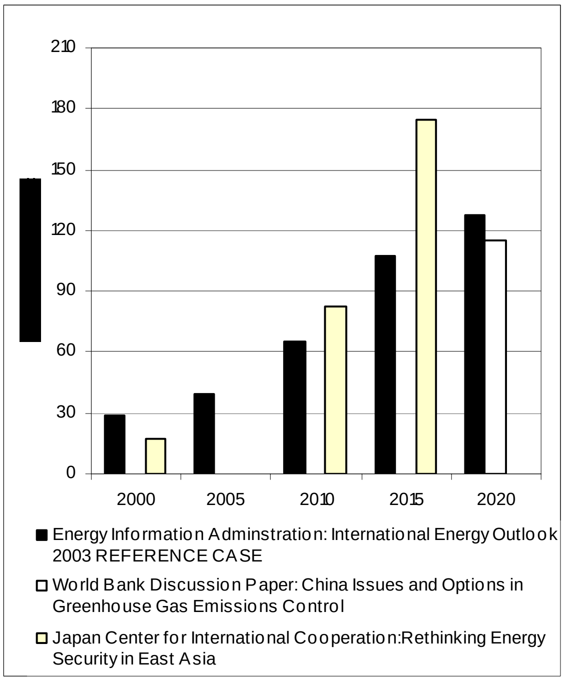

Figure 18

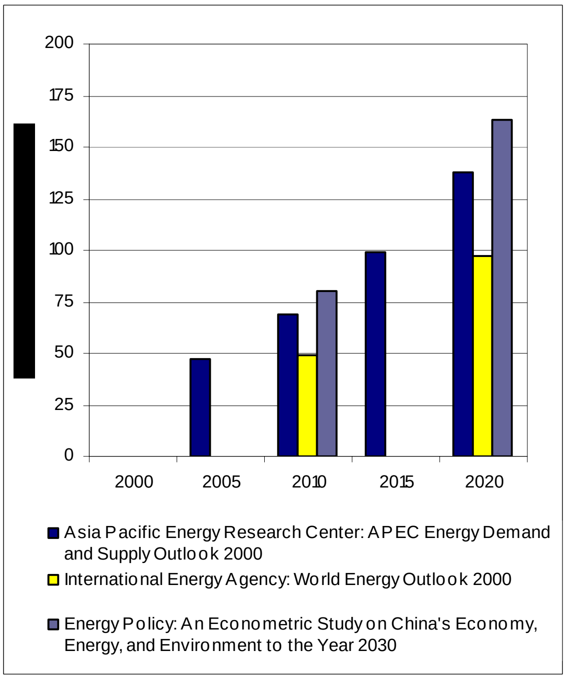

Figure 19

Natural Gas Demand: High Growth

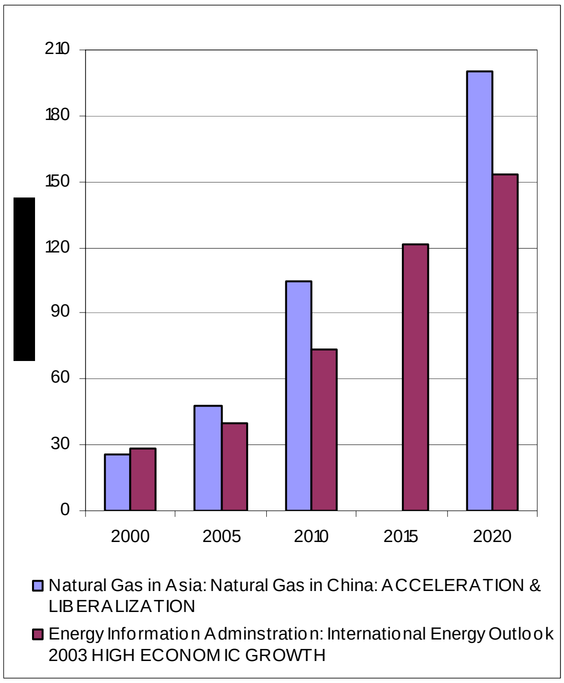

Figure 20

Natural Gas Demand: Low Growth

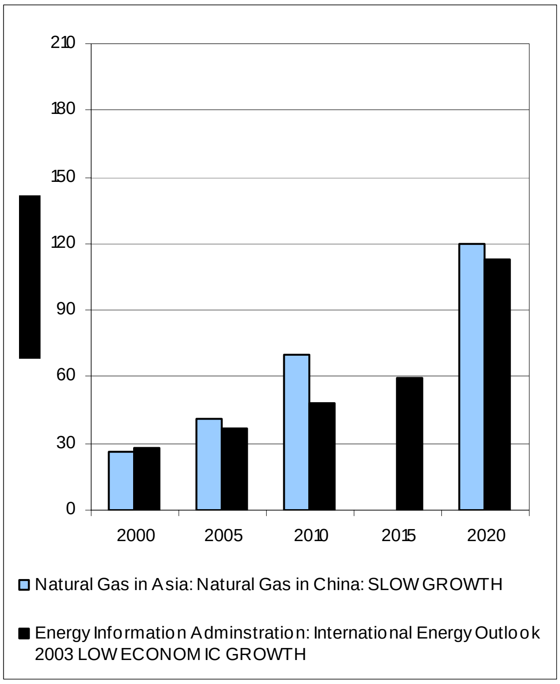

Figure 21

Natural gas consumption is slated to increase by 2020. Figures 18 and 19 reflect reference case scenarios with trends revealing consumption growth from all sources. Unit measurements vary between figures 18 and 19, but consumption patterns do not. Unlike natural gas production, where forecasted data showed little divergence, the rift between sources as to the amount of natural gas to be consumed in each of the five-year increments is more spread out. Because the consumption trends for all sources are the same, such data discrepancies do not impact the trend analysis. Along with the base scenario options, the EIA and David Fridley, author of “Natural Gas in China” have also projected consumption to be influenced by economic change. Both Fridley and the EIA project increasing natural gas use in both a high and low economic scenario. The difference between the two situations lies in the rate at which the energy is consumed. Were China to experience a drop in economic development, the country would continue to increase its use of natural gas, but the consumption rate would fall below reference case projections. In the context of accelerated economic growth, China would experience the same rising consumption trend, but is projected to use more gas than in the base scenario. China has shown steady natural gas consumption rates since the beginning of the last decade, in which consumption levels, like production capacity, grew. The forecasted natural gas pattern does not abandon the already established consumption pattern. Within the next two decades, the scenario studies project a continuance of the consumption trend from 1990-2000, in which natural gas follows an upward trend. Because the Chinese government pushes for a more significant natural gas presence in the energy balance, the forecasted consumption rates suitably follow not only government plans, but also the momentum set by consumption patterns from the last decade.

3.6 Nuclear

Nuclear Production

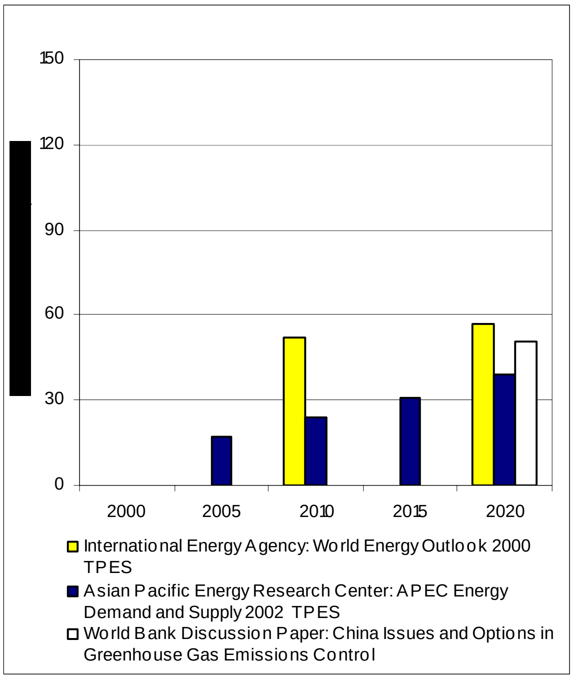

Figure 22

Nuclear Production: High Substitution

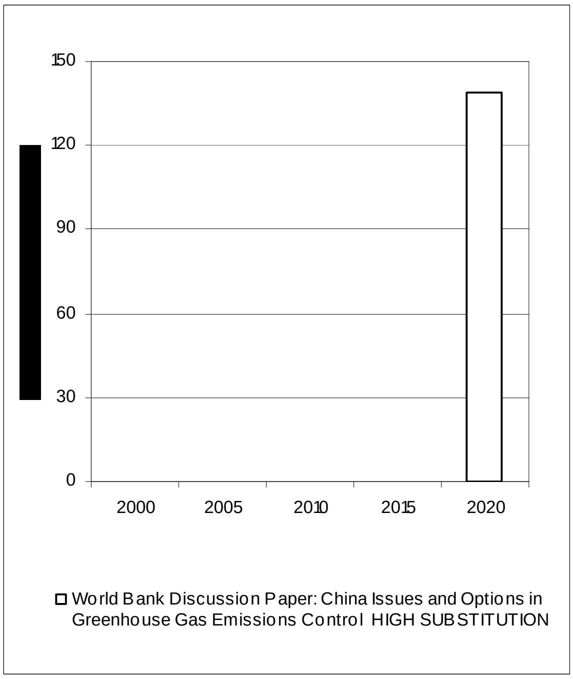

Figure 23

While forecasts focusing on nuclear energy are not common and many sources do not predict nuclear energy expenditures along a consistent time frame, the existing data in figure 22 suggests production to grow over the next two decades. This trend is reflected by all figure 22 sources. The World Bank provides an alternative scenario, one which considers nuclear production when the maximum amount of alternative energy sources is substituted in place of fossil fuels. Because the World Bank only offers data for 2020, no trend is present for this situation. What can be seen is that if China shifts emphasis towards alternative energies, nuclear production would increase over twice the amount produced in a “baseline” scenario. Since 1993, nuclear production capacity has enlarged from new plant construction. Nuclear production levels are predicted to increase by all available scenario studies and this pattern suitably fits into the production trend from the last decade. Because more plants are scheduled to go online in the next decade, the unbroken growth pattern projected by scenario studies for nuclear production is also compatible with government plans.

Nuclear Demand

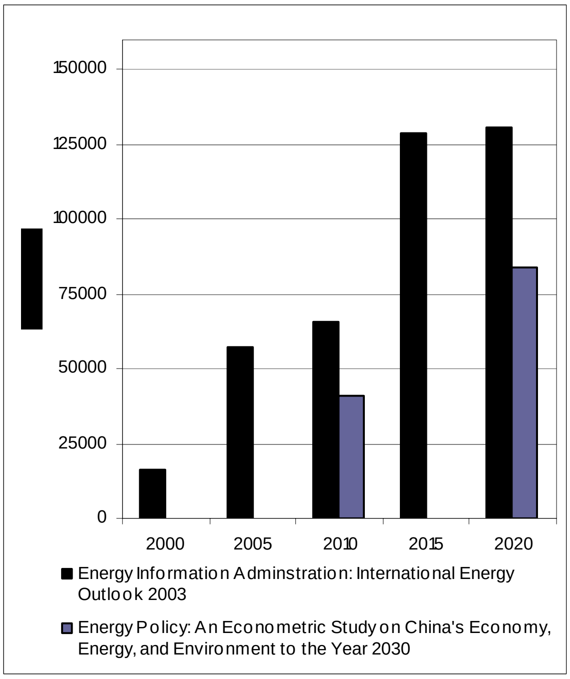

Figure 24

Nuclear Demand: High Economic Growth

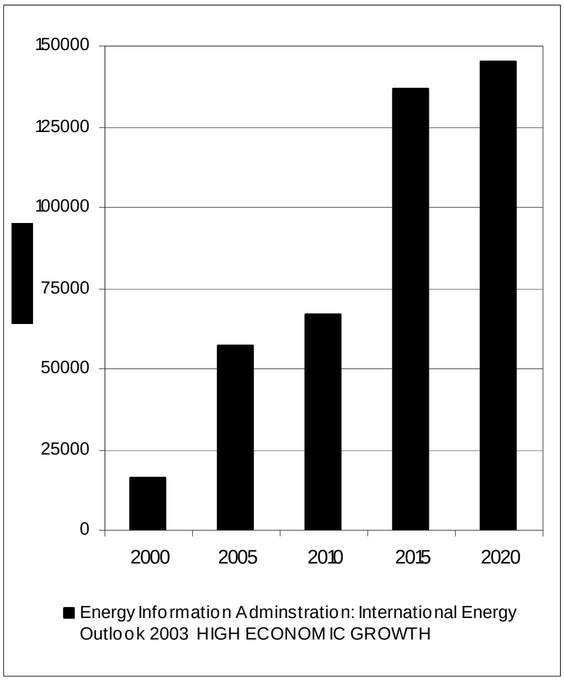

Figure 25

Nuclear Demand: Low Economic Growth

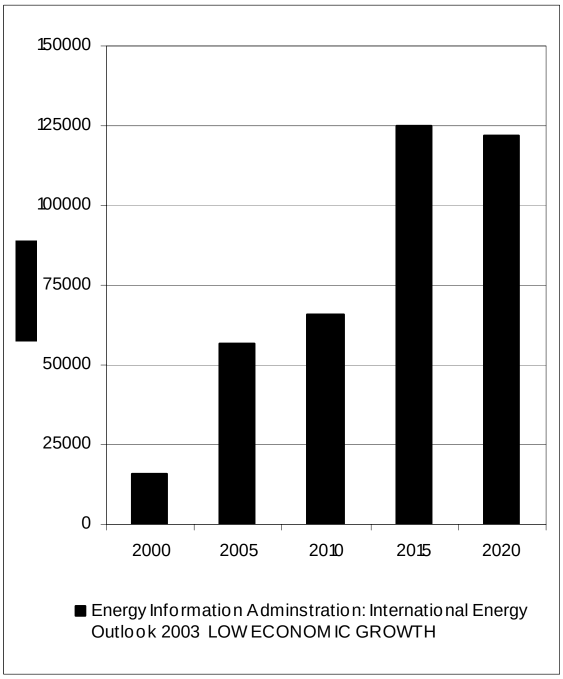

Figure 26

Figure 24 presents the reference case pattern for nuclear consumption, showing it to constantly grow over the two decade period. While one large data discrepancy exists between the two sources of 43,000 billion watts (GW), in general both reflect the same growth pattern. Along with a reference case scenario, the EIA has also constructed scenarios based on economic growth that either exceeds or falls short of the reference case economic situation. In both cases, nuclear consumption will increase. Figure 25, revealing data for high economic growth, suggests nuclear consumption levels to surpass present consumption rates in the reference case scenario. While figure 26 also illustrates growing consumption trend, the figures fall below those set in the reference case. Regardless of China's economic condition, all three figures illustrate a consistent increase in nuclear consumption for the next two decades. Much like the rising trend in nuclear production from the last decade, demand for nuclear energy has constantly grown since 1993. This unbroken, upward trend is projected to continue into the next decade as nuclear consumption is predicted to increase in all economic conditions.

4. Conclusion

This paper has outlined the energy setting upon which China's advancing automobile market may expand. Due to the inevitable link between energy, economy, and automobile development, the country's energy balance partially defines the direction of economic growth and automotive progress. According to the scenario studies used here, the energy balance in the next twenty years reveals a discrepancy between production and consumption. The growing private-car movement may confront high consumption rates and insufficient supplies. The industrial machine fueling China's exploding economy, rising residential power requirements, and inefficient energy-based technology aggravate energy consumption levels. China's automotive development face is consistently expanding. A continued, but decreasing dependence on coal, potential disparity between natural gas supply and demand, and a forecasted rise in nuclear plants exists.

This paper only considers the energy balance in the context of present and future situations. Past energy activities are also relevant when examining the future energy balance, as the energy mix from the last decades can reveal patterns that may follow in the future. For this purpose, a complete picture of the energy balance including past, present, and future expenditures must be laid. Because data from China's energy expenditure between 1990 and 2000 had already been collected in the discussion paper entitled "Leapfrogging into Hydrogen Technology, China's 1990 – 2000 Energy Balance," a general picture of the energy landscape can be erected by combining data accumulated therein with forecasted data assembled in this paper. While the means through which this picture is built are not entirely scientific, its necessity outweighs the scientific weakness. A visual image, revealing the patterns from past, present, and future energy expenditures is the most optimal method for understanding the energy landscape. These graphs serve as one means to link data collected from the first energy discussion paper with energy figures for the future. In light of slightly uncertain methodology, the following charts must be seen as a loose picture, revealing possible progress in China's past, current, and future energy balance.

Four graphs chart energy development from 1990 to 2020. These figures serve to bridge the two discussion papers. Because data for this paper are documented in five-year increments, for reasons of consistency, these charts contain data for every fifth year, starting in 1990 and ending with 2020. Each graph shows consumption and production levels from one of four energy sources (coal, oil, natural gas, and nuclear energy). Because differences among data for the same year exist and because China's consumption and production levels may respectively rise or fall, each chart presents possible high and low level boundaries. Taking the highest and lowest figure from each five-year increment, a high and low-level case is produced. In assuming scientific standards, such graphs require a single consistent data source, but sources used in the first energy study are different from those documented in this paper. As a result, each data point is inevitably derived from different data sources. Also, the highest or lowest production and consumption figure from each sector, for every five year increment, does not necessarily come from the same data source, creating graph lines built from many sources. This problem is especially recognized as scientifically problematic, since the means through which sources configure and derive data are different. The dissimilarities in methodologies in the various sources push these charts outside scientific guidelines. Nonetheless, a complete look at China's entire energy landscape, including possible future activities, balances the diluted scientific methodology used constructing such charts. Another factor which must also be pointed out is related to units of measurements. As described in the methodology section of both papers, some sources used incompatible units of measurement. Therefore, two separate charts for the same energy source were erected. Because only one unit of measurement can be used for these graphs, the data chosen for each point were derived from the unit of measurement most scientifically connected to each energy source.[8] The

[8] For coal, the most common unit is million metric tonnes, so only data presented with this unit were considered. For oil, the most scientific unit of measurement was also milllion metric tonnes. Natural gas is primarily

following charts must be considered with some reserve, yet, from examining the patterns found in both papers, the overall picture for each source is not unrealistic and effectively fits along the general trends already discussed in both papers.

Coal Consumption and Production 1990 - 2020[9]

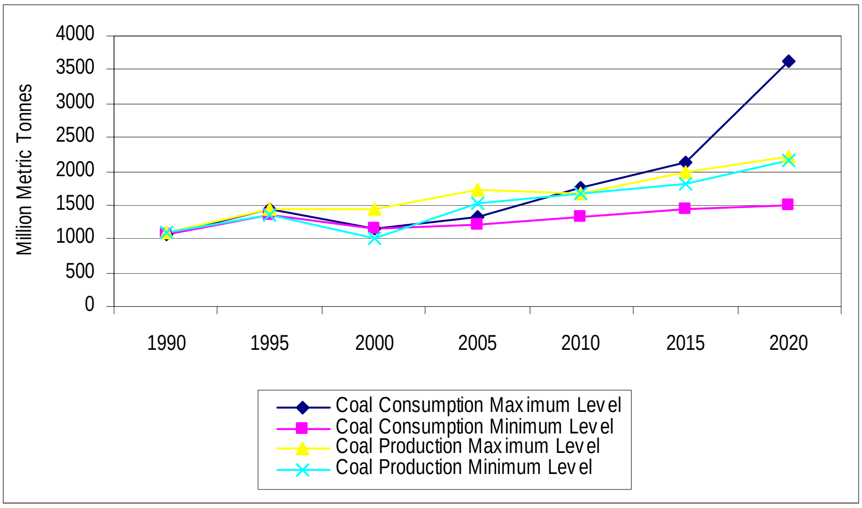

Figure 27

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documented in the form of billion metric meters. Nuclear energy data are calculated in terms of billion gigawatt hours. This means, that sources use measuring data in million metric tonnes of oil equivalent, the most common alternative unit of measurement.

9 Because numbers for each data point are derived from different sources, all sources used in constructing figures 28 – figure 30 are listed. Data for the coal consumption and production chart are taken from: International Energy Outlook 2003; Key Indicators of Developing Asian and Pacific Countries 2002;: International Energy Annual 2000 and 2001; United Nations 1994, 1998, and 1999 Energy Statistics Yearbook; Rethinking Energy Security in East Asia; Key Indicators of Developing Asian and Pacific Countries; World Bank Discussion Paper: China Issues and Options in Greenhouse Gas Emissions Control; Future Implications of China's Energy Technology Choices

Oil Consumption and Production 1990 – 2020[10]

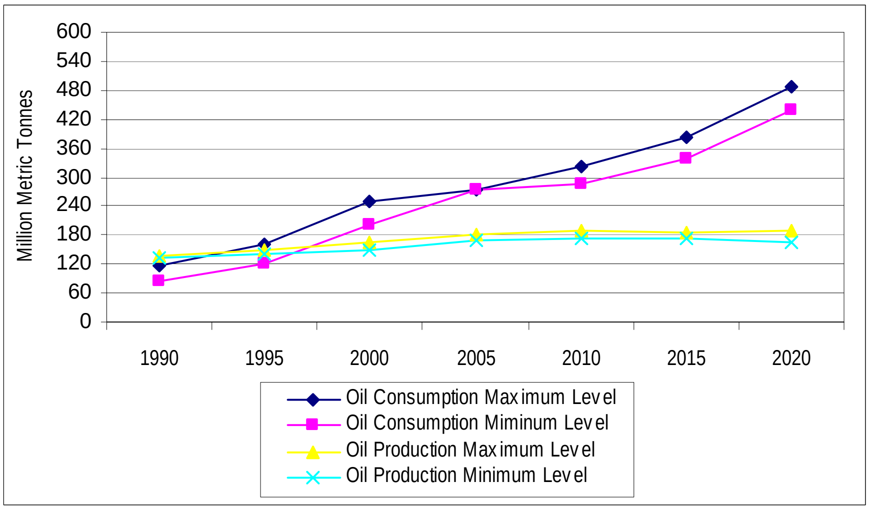

Figure 28

Natural Gas Consumption and Production 1990 - 2020[11]

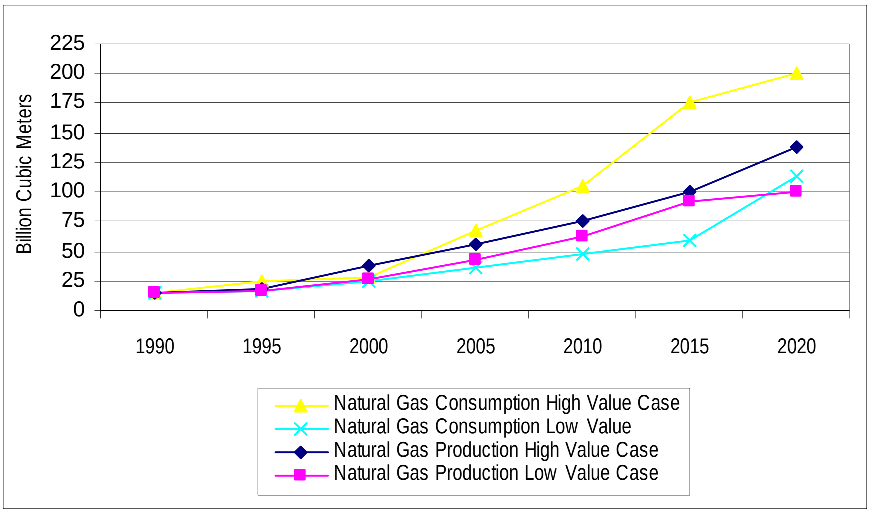

Figure 29

[10] Data for oil consumption and production are taken from; Energy Statistics of Non-OECD Countries; International Energy Annual 2000 and 2001; Key Indicators of Developing Asian and Pacific Countries; Rethinking Energy Security in East Asia; International Energy Outlook 2003; A Econometric Study on China's Economy, Energy, and Environment to the Year 2030; Asia Pacific Energy Cooperation Energy Database; China Energy Databook Version 5.0; BP Statistical Review of World Energy June 2002; International Energy Outlook 2003

[11] Data for figure 29, which outlines natural gas consumption and production uses the following sources: International Energy Outlook 2003; Natural Gas in Asia; China Energy Databook Version 5.0; An Econometric Study on China's Economy, Energy, and Environment to the Year 2030; Future Implications of China's Energy-Technology Choices; Key Indicators of Developing Asian and Pacific Countries 2002; Rethinking Energy Security in Ease Asia; China Energy Databook Version 5.0; Natural Gas in Asia; World Energy Outlook 2000; APEC Energy Demand and Supply Outlook 2002

Nuclear Energy Consumption and Production 1990 – 2020[12]

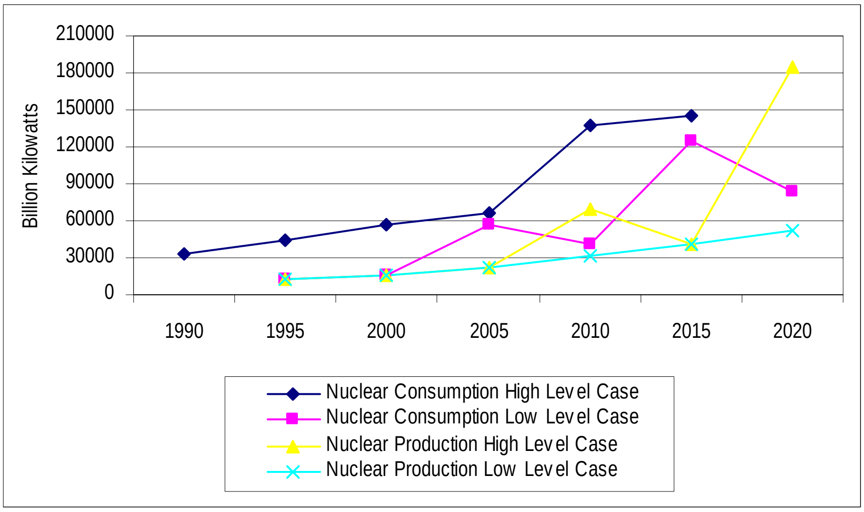

Figure 30

As a whole, the complete time charts delineating three time periods suitably represent China's energy landscape into the next two decades. China and its developing automotive sector have and will face an abundant coal supply. Yet, according to figure 27, China's large coal reserves will not quite meet supply demand in both the high and low level case (although low demand is met by high consumption). This discrepancy between consumption and production is not always present when single scenario studies are examined, in which coal consumption is effectively met by production rates. From a trend perspective, energy trends, consumption and production lines in figure 27 follow along the same, upward growth with all four lines closely clustering together. In comparison to the large discrepancy between production and consumption rates of oil, this minor difference in figure 27 can be read in relation to slightly faulty graph building methodology. Figure 28 creates a picture in which both supply and demand increase, with supply rates growing at a rate that is incompatible with demand. This is the general picture consistently presented by all data sources for the past, present, and future. China is building its automotive infrastructure against a diminishing oil supply. In combining an automotive society with insufficient oil supplies, the country confronts the persistent need for foreign oil support. This case not only affects worldwide oil supplies, but also distresses domestic and international energy security. Considering the rising car demands, China cannot domestically sustain its mobilization. Natural gas supply, in figure 29, also falls short of demand, a trend not uncommon among data sources. Although consumption and production levels do not sit on an even keel, between 1990 and 2020, both consumption and production trends show upward growth. The natural gas landscape appropriately fits along government intentions to expand both supply and use. The Chinese government has planned natural gas demand to be fulfilled by domestic

[12] Energy Statistics of Non-OECD Countries; APEC Energy Handbook; International Energy Annual 2000 and 2001; United Nations 1993, 1994, 1999 Energy Statistical Yearbook; Key Indicators of Developing Asian and Pacific Countries; BP Statistical Review of World Energy June 2002; China Energy Databook Version 5.0; APEC Energy Demand and Supply Outlook 2002; World Energy Outlook 2002; China: Issues and Options in Greenhouse Gas Emissions Control; International Energy Outlook 2003; An Econometric Study on China's Economy, Energy, and Environment to the Year 2030

supplies. According to the scenario studies used in this paper, from an infrastructure and resources perspective, this expectation cannot be feasibly met, as shown in figure 29. Of the four energy graphs, comparisons between nuclear consumption and production are most problematic. Ultimately, nuclear consumption and production will rise in 2020. Growth rates from figure 30 are not only sporadic, but also discordant. Neither high nor low level cases for production and consumption were correspondent, with figures rising and falling inconsistently in the five year increments. Methodology and data variability partially cause incongruent supply and demand trends, and the relationship between past and future supply and production, is one of constant growth.

Glancing at figures 27 to 30, as well as examining the data collections from this and the last energy study, China faces energy gaps on many fronts, especially in the sector most relevant to a traditional mobilization process. The gap between supply and demand in the oil sector grows wider each year and only foreign oil supplies can close it. Historically and recently, China satisfies energy demand through coal consumption cannot easily be reduced. Coal use has become and will continue to be an energy habit. Although reductions in coal have made room for natural gas and nuclear energy in the country’s overall energy mix, coal will continue to play a dominant, if slowly diminishing role in the energy balance. Natural gas serves as a suitable alternative to coal and oil use, but production capacity cannot fill consumption rates. Dependence on nuclear energy is rising. As plants are annually constructed, domestic production will meet internal demand.

Having relied on coal and oil for many decades, China cannot immediately restructure its consumption patterns. These energy dependencies are revealed in the forecasted energy balance, in which coal and oil remain primary sources in the energy make-up. Were the country to undergo a traditional motorization process, China could not avoid exacerbating its old energy-utilization habits. Only by building an automotive infrastructure that makes use of an alternative fuel can China rewrite the energy balance. From this perspective, adopting leapfrogging technology in the form of a hydrogen-based automotive infrastructure can be one option. Energy expenditures from the last decade already reflect slow, but well-intentioned efforts to exploit alternative resources. But coal will continue to play a large role in China’s energy expenditures, so the country must take it into account when considering hydrogen technology. China must find a way to exploit coal and renewable energies when erecting a hydrogen-based automobile society. Since hydrogen can be produced from renewable and nonrenewable energies, all of China’s resources, especially its vast collection of renewable energies and coal surplus, serve as an appropriate backdrop against which to adopt hydrogen technology. China’s developing natural gas and nuclear energy sectors ensure potential leapfrogging possibilities. While China uses minimal amounts of renewable energy, as suggested by the lack of appropriate energy data, the country is nonetheless endowed with valuable resources. And, enough infrastructure exists in biomass, solar, geothermal, hydro, and wind sectors to extend technology and resource development.

5. Measurement Units

Bbl	Barrel
Gm^3	One Billion Cubic Meters
GWh	One Billion Watt Hours
MMbbl/d	Million Barrels per Day
Mt	Million Metric Tonnes
Mtce	Million Tonnes of Coal Equivalent
Mtoe	Million Tonnes of Oil Equivalent

6. Appendix

Scenario Review

The scenario/forecast studies used in the data analysis and included in the methodology summaries are listed in Table 1.

Scenario/Forcast	Author	Published	Data Period
World Bankc Discussion Paper China: Issues and Options in Greenhouse Gas Emissions Control	Center for Strategic and International Studies Joint Report: The National Environment Protection Agency of China, The State Planning Commission of China, UN Development Program, and the World Bank	1996	1990-2020
U.S. Department of Energy China's Energy: A Forecast to 2015	Los Alamos National Laboratory and Pacific Northwest National Laboratory	1996	1995-2015
Japan Bank for International Cooperation Energy Balance Simulations to 2010 China and Japan	Research Institute for Development and Finance	2000	1990-2020
World Energy Outlook 2000	International Energy Agency	2000	1990-2020
Japan Center for International Exchange Rethinking Energy Security in East Asia Chapeter on China	Gao Shixian (Edited by Paul B. Stares)	2000	1990-2015
APEC Energy Demand and Supply Outlook 2002: China	Asian Pacific Energy Research Center	2002	1999-2020
Natural Gas in Asia: Natural Gas in China	David Fridley (Edited by Ian Wybrew-Bond and Jonathan Stern	2002	2000-2020
International Energy Outlook 2003	Energy Information Administration	2003	1990-2025
Energy Policy Journal: Future Implications of China's Energy-Technology Choices	Eric Larson, Wu Zongxin, Pat DeLaquil, Chen Wenying, and Gao Penfei	2003	1995-2050
Energy Policy Journal: An Econometric Study of China's Economy, Energy, and Environment to 2030	Li ZhiDong	2003	1999-2030

Table 1

7. Detailed Scenario Descriptions

World Bank Paper: China Issues & Options in Greenhouse Gas Emissions Control

Methodology

This study examines the relationship between economic development and greenhouse gas (GHG) emissions in China from 2000-2020. This model is macroeconomic model calculating future GHG emission consequences. While this study does not directly focus on China's energy expenditures, forecasted energy consumption nonetheless serves as a coefficient in the modeling system. The GHG model is composed of four sub-models: an econometric macroeconomic model, an 18 sector input-output model, energy consumption figures, and emission coefficients. The energy coefficient model determines coal, petroleum, natural gas, and electricity use from 18 energy-consuming sectors. Energy consumption trends are estimated in relation to the energy required for producing major commodities within these sectors. China's economic growth, new plant and equipment development relative to existing structures, rate of adopting energy-saving technologies, and increases in product diversity and product quality improvement affect energy coefficients in this model. Two scenarios for GHG emissions are assembled. A baseline scenario supposes Chinese economic patterns to continue along trends in the 1980's and early 1990's.[13] The baseline scenario also assumes energy efficiency improvements will continue. Two economic development scenarios were built under the baseline scenarios: a high-growth scenario assuming few political and social disruptions, high saving rate maintenance, and economic reform continuation; and a slower-growth case in which the economy grows at a slower rate (1.5%) than the figure calculated for high-growth scenario. For reference purposes, a business-as-usual energy demand scenario was prepared as another means through which to consider GHG emissions. A high-efficiency energy demand scenario is introduced under the baseline scenario umbrella. This is done to determine benefits of increasing energy-efficient technology levels. Here, consumption parameters are adjusted, especially for the industrial sector, so energy use resembles advanced international rates. Along with the baseline scenario, the study also produced a high-substitution scenario. This case reflects the maximum possible alternative energy sources utilized in 2020 following 1990 development trends.

Results

According to this World Bank study, energy consumption in the baseline case reaches 3,300 million tonnes of coal equivalent (Mtce). Economic growth, as measured in GDP, is predicted at 8.0% between 1990 and 2020. Because two economic scenarios are also constructed within the baseline scenario, GDP increase differs according to the speed at which the economy is assumed to grow. In the high-growth case, China's economy will grow at 8.0% from 2000 - 2010 and 6.5% from 2010 - 2020. When GDP is forecasted against a slow-growth case, average annual GDP is projected to increase by 6.5% from 2000 to 2010 and 5.0% from 2010 to 2020. Due to potential changes in the industrial production mix and sources of value added in industry, energy intensity should also fall.[14] A fall in energy intensity of 0.5% is projected for the next two decades. Along economic growth and energy intensity predictions, this study also provides

[13] The base year that sets the Baseline scenario is not specified.

[14] Energy intensity is the relationship between energy consumption and economic growth. It is calculated as the ratio of energy consumed over GDP growth.

forecasts over energy use. In the high growth GDP case, energy demand is predicted to grow at 4.1% per annum. The study's baseline case forecasts coal demand to tripple between 1991 and 2020. Consumption rates are set to increase by 3.7% p.a. Natural gas is predicted to grow 7% per annum while annual development in oil consumption is expected at 4.7% per year. Expansion in nuclear power production is also forecasted in this study. Because electricity is normally generated by coal, increases in nuclear consumption alleviate the reliance on coal. Coal consumption is expected to fall from 76% in 1990 to 67% in 2020. While the amount of coal consumed in China's overall energy mix is diminishing, this study forecasts coal for power generation to increase from 24% in 1990 to 42% in 2020. Industrial coal demand will also rise to 1,400 million tonnes (Mt) in 2020. Primary, commercial energy demand in the high-efficiency energy scenario reaches 2,840 Mtce, suggesting an energy savings of 460 Mtce when compared to baseline energy consumption. Although the study does not state specific figures, energy consumption by the transport sector is predicted "to be huge in absolute terms and relative to energy use worldwide." In the baseline scenario, fossil fuels provide 91% of the energy supply and 78% of power generation. Under the high substitution scenario, this percentage falls to 81% for total primary energy consumption and 61% for electricity production.

U.S. Department of Energy (DOE): China’s Energy. A Forecast to 2015

Methodology

This report considers China’s future energy production and consumption trends to 2015 in relation to U.S. energy security. China’s energy consumption is projected by sector (industrial, transportation, residential building, and agriculture) and fuel type. For this forecast, commercial and residential sectors are combined under the residential “building” sector. An energy intensity model is used for projecting energy demand through which historical energy intensity and sectoral GDP trends are analyzed. The study developed a “business as usual” (BAU) and “energy efficient” (EE) scenario from the energy intensity model. The study assumes validity in past consumption patterns and constructs the BAU scenario along current development patterns. The study does not specify a base year used for trend analysis, but the period 1995-2015 is examined in detail with trend charts beginning in 1980. Pre-existing trends were considered in relation to potentially new social and economic policies that could influence economic growth and energy consumption; energy advancement and trends from comparable countries undergoing similar development processes; and technology utilization tendencies and their implications for energy consumption. The energy efficient scenario is based on energy intensity reduction in major consumption sectors through strengthening energy efficient technologies. When examining fuel consumption discrepancies, this study assumes reduction in energy demand between the BAU and EE scenario results only in coal consumption. Because energy production is also explored, two scenarios: the “Standard Supply Scenario” which expects minimum production capacity and the “Maximum Supply Scenario” based on larger production capabilities were developed. According to this report, actual production tendencies will fall between the two scenarios. The Standard Supply Scenario assumes average growth rate to follow 1980 growth patterns, while the Maximum Supply Scenario assumes high energy production to not only emerge, but also to be maintained in 2015.

Results

From 1995 to 2015, the DOE report forecasts final energy demand to average 6.5% on an annual basis. Industry sector forecasts under the BAU scenario point to industry as the largest energy consumer with the final energy demand falling to 60% in 2015. Industrial energy intensity is also predicted to decrease as technology efficiency improves and fewer energy intensive products are manufactured. Industrial final energy requirements, largely fulfilled by the coal supply, are forecasted to reach 1,240 Mtoe in 2015. Residential energy consumption, primarily dependent on coal and biomass, will increase the fastest, growing from 2.7% of China’s entire energy demand to 7.3% final energy use. Energy use in this sector is forecasted to reach 357 Mtoe in 2015. Due to expanding road passenger traffic in the transportation sector, sectoral energy consumption is set to grow at 5.2% p.a. Because road usage has been consistently increasing, energy intensity in the transportation sector will decrease 2% p.a. until 2005 and then diminish by 1% until 2015. Increases in primary energy demand from the energy efficient scenario is approximately 1 percentage point lower, growing on average 5.7% per annum. Energy intensity, even under the EE scenario is not predicted to decrease drastically, as energy intensity under the BAU case is already very optimistic. The industrial sector, under the EE case requires 1150 Mtoe of energy in 2015 with the residential building sector to reach 324 Mtoe in the same year. Because diesel and electric locomotives are predicted to replace steam locomotives in the transportation sector, the energy sector under the EE scenario will consume 186.9 Mtoe and decrease in energy intensity by 3% p.a. Within the energy consumption balance, agriculture uses only 5% of total final energy, thereby ranking low in the energy-use sector. Due to the labor intensive, low technology farming strategy, coal dominates this sector's energy demand. Coal production has grown 4.65% on average and the Standard Supply scenario projects this growth rate to continue to 2015, whereas the Maximum Supply scenario predicts a 7.5% coal supply increase. According to the Standard Supply figures, oil production rates are set at 2.93% per year, while the Maximum Supply scenario production rates are slightly higher at 5%. Despite some growth in oil production rates, this report acknowledges China's rapidly rising import level. DOE forecasts China to import between 1.2 and 2.1 million barrels per day (MMbbl/d) in 2005 with figures reaching 5.8 to 8.6 MMbbl/d in 2015. Natural gas production figures resemble oil production growth for both scenario cases. 8.7 GW of generated nuclear power, as a result of technology improvements to existing plants and new plant developments, is forecasted for 2010.

Japan Bank for International Cooperation (JBIC) Energy Balance Simulations to 2010 for China and Japan

Methodology
This JBIC study centers on building a database from which an E3 (energy environment economy) model is constructed from an existing framework. In this context, a sectoral model projecting China's energy balance for the next decade is also erected. What is ultimately produced is an energy balance forecast using the newly designed model, the Energy Environment Economy Model for the Globe (E3MG). Energy forecasts are based on a baseline simulation of energy demand for China to 2010. Along with baseline energy forecasts, the study also considers the energy expenditure patterns from a high economic growth case. The Chinese economy in the E3MG model is forecasted by "establishing dynamic behavior from the time-series data over the post reform period." This econometric model contains a data problem since suitable Chinese data before 1980 is difficult to obtain. As a consequence, the time series used for the energy and economic growth projections covers the period between 1984 and 1995. Econometric models also assuming institutional structures are fixed over the data period. In China's case, this assumption is unrealistic, so in the E3MG model, calibration is used to ensure the model has access to the most current data. Data for the model was arranged in four stages, in which a databank is constructed and organized with a computer program created to fill gaps in any time series. Macroeconomic data is placed into the databank for consistency and such data is collected from unstated, but recognized international sources. The JBIC estimates a set of energy equations for China, covering total energy demand by 17 fuel users from industrial and household sectors. The model takes a two-tier approach to energy demand. At the top level, aggregate demand for all energy types is presented while the bottom level is based on fuel share equations for primary energy estimated for the 17 fuel users. Population growth, output by 32 industries, GDP growth, industry investment, and energy prices, in connection with energy demand equations were combined to project energy demand for the next decade. This model uses energy consumption data from the China Statistical Yearbook and China Energy Statistics, while numbers for national accounting are drawn from the "Annual Report on National Accounts." Because the model uses domestic data, data compatibility and energy consumption definitions problems arise. Not all figures from each source are directly comparable to the other, while certain fuels are not covered in the data sources.

Results
Assumptions for economic growth are made at the level of 32 industries and according to the business as usual outlook, GDP is expected to grow annually by 7%. Overall energy demand is expected to increase yearly by 1.5 to 2%. A shift in industry towards less energy-intensive activities and priority placed on energy efficiency by some sectors is slated to ease energy consumption. Such a change is represented in a forecasted 5% annual fall in energy intensity by 2010. A reduction in population growth (increasing yearly by 1.5%) is also expected to influence energy consumption. The JBIC predicts growth in 17 dominant, energy-based industries, of which the electricity sector is considered to expand the fastest. For the purposes of this study, only transport growth statistics are recorded. According to this report, rail and road transport are forecasted to grow at 6.6% every year, with air transport measuring an annual increase of 8.0%. The JBIC study predicts investment in the transport industry, along with transport growth, to also swell. For road and rail transport, investment increases annually by 9.1%. Energy demand is expected to intensify in the next decade, so this study forecasts energy prices to grow yearly by

5%. In 1990, 7% of China's total energy demand was satisfied by coal use, but coal consumption figures fell drastically toward the end of that decade. From 2000 to 2010, growth in coal demand is expected to remain flat and reliance on this energy in China's overall energy balance is forecasted to fall below 50%. Oil consumption is expected to grow between 4 and 4.5%. According to this study, the rate of oil consumption is consistent with consumption figures over the last ten years. Oil is predicted to cover 27% of the energy balance by 2010. This energy simulation projects natural gas demand to increase annually by 3.5 to 4%. The JBIC predicts the service sector to harbor the fastest growing energy demand. Such an increase is coupled with a high-energy intensity level for this sector in the next decade. Along with the service sector, energy demand from the transport sector is forecasted to rise annually by 2.5 to 3.5%. Predictions over oil demand in the transport sector range between 3 to 4%. Along with baseline forecasts, the energy simulations also consider China to experience high growth. In this case, GDP is expected to escalate by 9.3% per annum with energy demand to also increase at 2.5%.

International Energy Agency (IEA) World Energy Outlook 2000

Methodology

The IEA uses a world energy model (WEM) for long term energy projections. WEM is a mathematical model composed of four sub-models: final demand, power generation and other transformation, fossil fuel supply and emission trading. The model calls for exogenous assumptions in GDP, population, international fossil fuel prices, and technological development. Exogenous assumptions, combined with outputs from three regional modules (final energy demand, power generation, and fossil fuel supply) are used to project country-based energy balances. The IEA's Energy Statistics Division provides the historical, economic and energy data needed for the WEM. Module equation boundaries are determined econometrically using time series data from 1971-1997. Adjustments to equation parameters are sometimes made by econometric and calibration techniques when expected structural, policy, or technological changes arise. Because some transition economies lack reliable data for the entire time series, cross-country analysis or expert judgments are substituted for an econometric estimation. Three regional modules used in the WEM for energy balance projections are also broken down into sub-sectors. The standard module for total final energy demand models nine sectors (industry: iron & steel; chemicals; other industries; transport: road, aviation; other transport; residential; commercial & services; agriculture) with final energy demand defined as the sum of energy consumption from all sectors. The sectors in this equation and final energy demand are considered in terms of end-user prices, economic growth, population adjustments, and potential structural/technological adjustments. The IEA also points out that some non-OECD countries, due to a lack of necessary information, must be modeled along a less-detailed energy demand equation, but no further details are offered as to which countries required a modified equation module. The power generation module calculates necessary new generating capacity, intended plant development, electricity generation by plant, fuel consumption for electricity demand, and electricity generation costs. The World Outlook calculates peak load by relating electricity demand with assumed load curve. This figure is then combined with a minimum reserve plant margin and compared with existing plant capacity to determine new generating capacity. Choice of new generating capacity is also made on the basis of levelized cost, which examines capital and operating and fuels costs for the life of a plant. Eleven different plant technologies are taken into account. Nuclear and renewable electricity plant capacity forecasts are generated through exogenous assumptions with impacts from international fossil fuel prices. The regional fossil fuel supply is forecasted through an oil, gas, and coal module. The oil module calculates oil production levels for each region with production divided into non-OPEC, OPEC, and unconventional oil production. A short-term approach investigates production profiles according to field-by-field analysis. A long-term analysis places emphasis on determining production rates according to ultimate recoverable resources and a depletion rate estimated from historical data. The natural gas module is also constructed along a resources approach. Unlike the oil module, four regional markets: America, Europe, Africa, and Asia are examined whereas the oil supply is factored on a single international market. Net importers and net exporters are modeled. When gas production from importing countries is measured, the remaining regional demand is transferred to exporting countries. Along with oil and gas models, coal supply is also separately analyzed in the fossil fuel supply module. The WEM reasons that sufficient coal reserves exist to fulfill the international demand. Coal reserves, from an IEA perspective, are also more evenly distributed worldwide. So, no coal model has been constructed under the WEM, rather, coal prospects are separately considered for each region.

Results

Economic growth, measured according to GDP is projected to increase annually by 6% to 2010. This study forecasts, on average, a 5% GDP growth for the entire outlook period, which ends in 2020. The Chinese population is estimated to reach 1.4 billion by 2020. The IEA projects the population to increase at 0.7% per annum. Total primary energy supply is projected to grow by 3.4% p.a., reaching 1940 Mtoe in 2020. According to this outlook, China has the world's largest per annum incremental energy demand growth. Total primary energy consumption may double by 2020. Energy intensity is expected to slowly decline, averaging an annual 1.8% drop. Coal will remain the largest energy producer in 2020. Coal demand, nonetheless, is expected to diminish. Much of this demand stems from the power generation sector. In 2020 coal will account for 62% of the energy balance (as compared to 72% in 1997). Demand for oil is forecasted to rise to 28%. Oil consumption is affected by growth in the transport sector, which pushes up the annual growth in oil demand to 4.4%. While natural gas demand will increase by 7.5% p.a., it only covers 6% of the 2020 energy balance. Nuclear energy will show strong growth, measuring around 10.5% p.a. for the next two decades. Despite the increase in nuclear consumption, it only represents 2% of the energy balance. Coal demand is projected to grow 2.6% a year, but demand will nonetheless measure 1192 Mtoe by 2020. The dominance of coal in the energy balance is expected to plummet from 54% in 1997 to 35% in 2020. Oil in the energy balance, in contrast, will rise to 36% of the final energy consumption. Industry holds the ranking having the fastest growth in energy demand. The transport sector will consume 17% of China's energy in comparison to its 13% in 1997. Oil consumption in the transport sector is spurred by rising mobility, with road transport fuel demand serving as a large impact in oil demand from a transport perspective. Regardless of the rising oil demand, oil production is projected to fall in the medium term. Such an imbalance between supply and demand implies imports of 5 million barrels per day (Mbbll/d) by the middle of the import period. Expected production, in the long term, should decline 2.6 Mbbl/d, with demand to rise by 11 Mbbl/d, resulting in exports exceeding 8MMbbl/d by 2020. Oil import increases from 22% to 76% in 2020.

Japan Center for International Exchange (JCIE): Rethinking Energy Security in East Asia

Results

Because this outlook does not clarify methodology, only results from the energy projections from 1995-2015 are presented. In forecasting energy developments, 1995 serves as the base year. All projections are based on author expertise and the Chinese Statistical Yearbook. According to this outlook, China's economy is set to grow at an annual rate of 7.4% until 2015. Energy demand from secondary industry is expected to decrease from 73.5% in 1995 to 65% in 2015, while tertiary industry will use more energy from 10.2% in 1995 to 17.0% in 2015. While coal takes up a smaller chunk in China's future energy balance, it will nonetheless retain the dominant position. Coal consumption is expected to fall from 77.9% in 1995 to 60.8-63.3% in 2015. Natural gas is predicted to possess 9.8 to 12.1% of the energy balance, a large development as compared to its 1.9% share in 1995. Such projections assume investments in necessary energy infrastructure to proceed as planned. In case such plans are not carried out, coal assumes a larger energy balance portion, measured at 65% by 2015. A rise in energy production is also forecasted, but production figures for coal and oil are projected to fall, while the natural gas supply is expected to rise, absorbing roughly 7% of the 2015 energy balance, as compared to 1.9% in 1995. This study forecasts China's future oil demand to push the country into a third place oil importing ranking, falling behind the United States and Japan for using external oil supplies. Net oil imports of 90 - 100 Mt and 125 – 145 Mt are forecasted for 2010 and 2015, respectively. Such figures suggest imports will consist of approximately 32.7-34.6% of the oil supply in 2010 and 38.5-40.9% in 2015. Imported natural gas is also expected to make up a large portion of the supply, forecasted at 22.7-24.4% in 2010. This study relies on figures from China's Electric Power Department in forecasting nuclear power developments. Nuclear power supply is expected to reach 15 – 20 GW in 2010. Projections for nuclear capacity, when larger plants become operational, range between 30 to 35 GW.

Asia Pacific Energy Cooperation (APEC) Energy Demand and Supply Outlook 2002

Methodology

The APEC outlook covers the future energy activities of all 21 member countries, including China, from 1999 to 2020. Chinese energy expenditures are not only considered as a single unit, but China's energy patterns are also compared and examined in relation to the APEC region. Due to the study's dimensions, it is not necessary to explore China's energy activities in the context of other APEC countries, so this scenario description focuses only on forecasted energy data on China. This energy outlook developed a "reference" or "business as usual" scenario with 1999 serving as the base year against which the scenario is built. Energy supply and demand is separated according to energy types. When possible (depending on data quality and quantity), econometrics served as the methodological approach for demand side analysis, using a time series from 1970 or 1980. What is not specified is whether the outlook applied a 1970 or 1980 times series in developing the Chinese energy forecasts. Because the energy landscape transforms quickly in one decade, the start period on a time series heavily influences the forecast outcomes. From a methodological perspective, the ambiguity connected to the time series start point detracts from the forecast's methodological validity. Along with this methodological problem, the Outlook lacks a detailed specification as to which econometric model is taken to produce data. Because econometrics models vary in theory and mathematical approach, without details clarifying how econometrics is used and which model is adopted for scenario building, the methodology undertaken must be clarified to understand how the energy data were determined. The assumptions made for supply-side analysis is also methodologically unstable as supply is assumed to match demand, but a rationalization for such an assumption is not offered. Energy-related policies implemented during the base year time were integrated into the forecast. When predicting energy consumption and production levels, this scenario does not consider energy-related impacts except already established effects such as global warming. Also not included in the scenario development are any speculative technology improvements. IEA energy serves as the main data source for this outlook and is supplemented with data from the APEC energy database and direct data contributions from member experts and sources. Because external factors such as GDP and sector growth ultimately affect the energy balance, APEC commissioned DRI-WEFA to supply such projections. APEC gives no methodological detail as to how this organization approaches forecasting. DRI-WEFA was contracted to supply GDP and population forecasts for all member countries. The Asian Pacific Energy Research Center reasoned that input consistency is necessary for scenario building, so used an outside source for input forecasting instead of basing the scenario on official government predictions. Energy forecasts are structured along the standard format for Energy Balance Tables (EBT), which includes all energy sectors as well as major energy forms. Some modifications were made to the EBT format: Coal and coal products fall under the category "Coal," crude oil and petroleum products are combined under "Oil" and natural gas and town gas are referred to as "Gas." In text and tables, "natural gas" is used to refer to the primary energy, in an effort to maintain clarity.

Results

Because the APEC Outlook connects energy developments to economic and population growth, economic growth prospects and population changes are also factored into the energy scenario. Within the Asian Pacific Economic region, China maintains the highest economic projection for 1999-2020, at 7.2% per year and a 2.7% energy consumption rate. The outlook bases such a projection on domestic demand and foreign investments, both of which are hastened by the country's WTO accession. Chinese population levels are expected to decrease in the next two decades, falling from 0.7% per year from 1.1% growth in the previous decade. The APEC Outlook builds an energy scenario according to the assumption that energy production and consumption is driven by economic growth, so data is developed against the energy required to support China's projected economic growth. Although this scenario examines total energy consumption, the outlook also breaks down consumption levels along specialized areas: industrial, transport, and residential sectors. China's industrial sectors are projected to consume roughly 601 Mtoe Equivalent in 2020, with an energy intensity projected to decline at 4.2% per year from 1999 to 2020. Energy consumption in China's transport sector is measured at 205 Mtoe by 2020. In other words, the Outlook predicts a 5.3% yearly growth rate for the next two decades. The APEC Outlook further separates energy consumption in the transport sector along modes of transportation. Energy consumption from road transport is forecasted to grow annually at the rate of 4.9%; air transport at 7.8%; marine transport at 6.8%; and rail transport, with the slowest energy growth rate, at 4.7% p.a.. In the past, energy consumption in China's residential and commercial sector was predominantly centered on coal usage, but in the forecast period, coal demand is expected to decline. Along with a decrease in coal consumption, natural gas reliance should increase from 4.8 Mtoe in 1999 to 24 Mtoe in 2020. As previously stated, the scenario paints an energy intensity decrease from all social sectors, and according to this scenario, energy intensity is predicted to decrease overall from 3.7 tonnes of oil equivalent (toe) per million U.S. dollars in 1980 to 0.5 toe/million $ in 2020. According to APEC, the country's rapid economic growth and shift into energy-efficient technology utilization spurs the fall in energy intensity. Oil production is predicted to fall slightly in the next twenty years, while the Outlook expects China's coal production to grow annually by 2.4%. In conjunction with slight growth in coal production levels, Chinese coal exports are also expected to jump from 25 Mtoe in 1999 to 67 Mtoe in 2020.

Natural Gas in Asia, The Challenges of Growth in China, India, Japan, and Korea: Natural Gas in China

Results

Because this study is not intended as a detailed natural gas forecast, the methodological approach used to generate expenditure figures is not outlined. Rather, this study presents an overview to developments focusing upon augmenting the natural gas share in the market. In the process, this study questions China's target of 10% natural gas consumption in the overall energy balance. While 10% remains a relatively minor share in China's overall energy mix, such a percentage translates into a large absolute volume, amounting to roughly 200 billion cubic meters (bcm). This figure is reached by using primary energy consumption in 2000 (1.27 billion tonnes of coal equivalent) and assuming 2.5 to 3.5% annual growth in primary energy consumption for the next 20 years. The author cites Chinese geologists pointing to the potential for natural gas expansion. The second national survey for petroleum and natural gas resources in 1994 is used as the basis for current estimates. This survey claims that 48% of sedimentary areas have yet to be explored for natural gas pockets. PetroChina, however, plans to increase gas reserves by 1.9 to 2.3 trillion m^3 by 2010. Along with conventional natural gas resources, China also possesses stores of coal-bed methane (CBM). While the country has set CBM production targets to 3-4 bcm in 2005, 10 bcm in 2010, and 20 bcm in 2015, geographic complexity and technology incompatibility may bar China from reaching its planned yields. In 2020, natural gas production is not expected to satisfy consumption levels with potential shortfall ranging from 10 to 108 bcm. Production projections are based on expansions of proven gas reserves. This study estimates demand to range from 75 to 80 bcm in 2010. The author points out that international sources place 2010 demand on a higher level at 120 bcm, so when comparing such demand estimates to China's planned 70 bcm production figure, import figures could range from 0 to 50 bcm. The dimensions of the natural gas industry for the next decade are already shaped. This outlook suggests the combination of an immature gas industry, emergence of new policies and plans at the end of the 1990's and beginning of 2000 positions the country in a "learning phase" in which market, institutional, and infrastructure development, along with international interchange paves the road for supply capacity and industry expansion. In the next decade natural gas will remain a domestic concern as reserves are increased and new gas fields are discovered. But if the country wants to widen its market beyond domestic supply supported by imported LNG, as reflected in the "slow growth" scenario, China must build fixed links to international gas fields. Such a strategy calls for long term bilateral or multilateral contracts with foreign regions. Without international pipelines, growth in the natural gas production will be limited to 100 bcm in 2020. Another challenge China confronts for natural gas expansion is acquiring a sufficient market to utilize supplies at gas prices equaling those found in industrialized countries. The study concludes by emphasizing the need for multiple external supply lines for China to reach its 10% natural gas share.

Energy Information Agency (EIA) International Energy Outlook 2003

Methodology

Published and compiled by the Energy Information Administration (USA), the International Energy Outlook 2003 presents energy consumption forecasts of industrialized and developing nations. Projections for all countries, including China extend to 2020. The outlook offers three energy scenarios for the next two decades. Using the System for the Analysis of Global Economy Markets (SAGE) as the forecasting model, a reference case or baseline scenario is established. High and low economic growth forecasts are based on the reference case scenario. Because China's economic progress in the last decade reflected rapid advancement, the possibility for an extreme downturn also arises. Using this reasoning, 2.5% is subtracted from the reference case growth rate to represent a low economic growth. For a high economic growth scenario, 1.0% is added to the reference case figure. Economic growth, for this outlook, drives energy consumption activities. The outlook measures growth in terms of GDP and uses projected data supplied by Global Insight Inc. Because the outlook does not offer further information regarding the forecasted GDP figures, the specific approach Global Insight Inc. uses to project future GDP numbers is not clarified. Unlike the GDP projections, the model through which the reference case energy consumption data are reached is fully detailed. The SAGE model, a more complex version of the well-used MARKAL model, is also a partial equilibrium, technology explicit model. SAGE integrates a set of regional models providing a technology-rich foundation for estimating regional energy consumption. A reference case projection is generated for each region using 42 end-use energy service demands. These factors are developed through economic and demographic projections. How energy consumption patterns can meet energy demands are considered in terms of the region's existing energy use patterns, existing energy-use equipment, characteristics of available new technologies, and new primary energy sources. Energy-relevant government policies implemented by October 1, 2002 were used for the reference case forecast. SAGE figures regional energy services at least cost by simultaneously making equipment investment/operating decisions with primary energy supply decisions. This is completed using "period-by-period, market simulation."

Results

Chinese GDP growth is forecasted to undergo a 6.2% average annual growth rate. The outlook forecasts energy consumption to increase at an average annual rate of 3.8%. Were China to experience high economic growth, this figure would increase by 0.7% and on the occasion the country suffers from low economic development, energy consumption is projected to fall to 2.1% per year. According to the IEO outlook, oil demand has and will continue to climb, predicted to increase annually at 3.3%. By 2025, China will consume 10.9 MMbbl/d, much of this oil is projected to be imported. The predicted rise in oil consumption is intimately connected to the forecasted transport growth. Almost all projected escalations in petroleum product reliance and two third increments of China's predicted oil demand are fueled by transport. Road transport will have the largest impact on oil consumption for the next two decades. Air transport is projected as the second highest growth area in the transport sector. The outlook expects natural gas demand to grow most within developing nations, including China. Increases in natural gas reliance are connected to electricity generation. The outlook also predicts natural gas to displace home heating and booking fuels in Chinese cities such as Shanghai and Beijing. The Chinese government, partially motivated by the Beijing 2008 Olympics, is pursuing natural gas production, transportation, and importation. Already, PetroChina has built the West-to-East pipeline, extending from the gas rich Tarim Basin, Xinjiang to Shanghai. The eastern side came online in 2003 and the western half was scheduled for launch in October 2004. The country is negotiating with Russia for an annual 700 billion cubic feet gas import through an extension of the West-to-East. This natural gas exchange, from Russia’s Kovyta field, may begin in 2008. Coal consumption in the forecasted period is dominated by China and India. China is expected to fulfill much of the increased energy demand through coal, especially in the industrial and electrical sectors. In 2001, 62% of the coal used in China was for non-electricity purposes. However, such heavy coal reliance from the industrial sector is forecasted to decline to 52% by 2025. Dependence on coal for electricity generation, which is not explored in this paper, is predicted to increase every year by 4.2%. Along with domestic coal reliance, the outlook also predicts China to account for a significant portion of Asian coal imports. Chinese import figures could result in a potentially higher figure, but this outlook forecasts that projected increase will be satisfied by domestic production. China is forecasted to use 19 GW (Gigawatts) of nuclear power in 2020.

Energy Policy Journal (EPJ): Future Implications of China's Energy-Technology Choices

Methodology

For this study, technology scenarios are used to explore China's evolving energy system, so developing a forecast for China's energy expenditures is not the main purpose. Because the modeling system used in scenario building calls for energy inputs, the study produces energy production and consumption data for China's future. For the study, a MARKet-ALlocation (MARKAL) energy-system model was constructed for China and used to analyze alternative technology strategies China could adopt from 1995-2050 to diminish the country's growing energy challenges. This MARKAL model is a linear programming model identifying the technological configuration for an energy system. This study develops two technology scenarios for China's energy landscape. The first model runs a "Base" set of energy conversions, energy-based technologies currently available or at advanced development stages. This business as usual scenario examines the results of a country following along current energy-supply technology trends in which technology is slowly improved. The second scenario adds the "Advanced" set of energy conversion into the modeling process. Technologies still in the research and development phase are categorized as "Advanced." This scenario is constructed to examine China when leapfrogging upgrades are included in the energy system. Both scenarios are overlaid with one or more constraints: limits on SO_2 emissions; oil and natural gas imports; and CO_2 emissions limits. So, four sub-results are developed from the two overarching scenarios. In the MARKAL model, costs, maximum supply of primary energy resources, the cost/performance characteristics of alternative conversion technologies for processing primary energy sources, the cost/performance characteristics of alternative end-use technologies, must be specified. The authors projected energy demand by comparing historical data for OECD countries at similar per capita GDP levels. By assuming China to expand energy services that match the level achieved by OECD regions in the mid-1990's, the authors were able to make energy estimates for the next five decades. Demand for energy services is tied to planned, future economic growth. Energy production estimates represent the absolute limit on annual production as specified in the MARKAL model, but is not necessarily the level at which the resources are used in the model. Factors connected to energy growth such as forecasted GDP and population patterns are based on baseline data from China's State Economic Information Center. The authors made low GDP projection based on recent trends in China's energy expenditures. While the study does not present specific figures for future energy consumption, the MARKAL model does generate an outlook for future energy demand, differentiating energy consumption in primary fossil fuel sectors based on the two scenarios.

Results

Forecasted GDP rates suggest 7.0% growth until 2005 and 5.5% increase from 2010 to 2025. The study projects population growth as ranging from 0.7% in 2005 to 0.43% in 2025. Between 1995 and 2050 the study estimates energy service supply to more than triple. Energy intensity declines at 3.5% per annum. Projections of coal production show a 1.5% annual growth until 2050. Oil production peaks at 180 Mt per year between 2015 and 2025, after which production is expected to fall around 100 Mt. Natural gas production growing through 2020, reaches a 170 Billion m^3 upper bound. Natural gas growth rate over this period averages 4.1% a year. Minimum installed nuclear capacity varies in projection from 19 GW to 216 GW in 2050. Projection is guided by recent investments in new exploration and current pipeline development. Coal is the dominate energy in BASE and B-SO2 scenarios. Primary energy use is lower in B-SO_2 (Base scenario with constraints on SO_2 emissions) as compared to BASE due to substitution of coal with natural gas in the industrial sector. Oil and natural gas imports in BASE average 280 Mtoe 51 percent imports (China imported 65 Mtoe in 2000) B-SO2 scenario number decreased to 203 Mtoe. When carbon dioxide emissions are set to 80 GtC, natural gas and oil imports climb to 988 Mtoe in 2050. China under the "Advanced" scenario option, in comparison with the Base scenario cases, requires less oil and gas imports, in comparison with the country under the Base scenario. When further limits on SO_2 and CO_2 are imposed on the "Advanced" scenario, coal consumption experiences a reduction as renewable and alternative energies replace typically coal dominated services. The study makes a particular energy use comparison between the B-SO_2 scenario (B scenario) and the A-S-O30-C66 (A scenario) upon which restrictions are set on SO_2 and carbon dioxide emissions are limited to 66GtC. According to this comparison, primary energy use in scenario B grows to 110 EJ in 2050. Energy use in scenario A grew faster to measure 139 EJ, but fossil fuel consumption is 8 EJ lower than the B scenario. China, under scenario B, continues to be dominated by coal consumption, consisting of 64% of the energy balance at the end of the next five decades. While coal reliance in scenario A is not starkly different, direct coal use is significantly decreased as compared to direct coal dependence in scenario B. In scenario A, industry, residential, and commercial coal use diminishes, but coal use for electricity generation increases considerably to 56% by 2050. Oil and natural gas consumption's contribution to the energy balance remain largely unchanged under scenario B. The study predicts oil production to peak in 2020, so oil imports in scenario B will reach 320 mt by 2050 accounting for 76% of oil use. Scenario B also predicts natural gas imports to grow in 2010 where 56% of gas used will be imported. But, due to heavy coal dependence and oil imports, natural gas consumption is not expected to grow after 2035, spurring an import reduction. From a scenario A perspective, the share of oil and natural gas in China's energy mix drops from 21% in 1995 to 13% in 2050. The diminished oil dependency stems from installing oil-efficient vehicles in the transport sector, a transition from conventional vehicles to hybrid-electric cars, and adopting fuel cell vehicles operating on coal-based hydrogen. Natural gas demand intensifies in scenario A, requiring the country to import 30% of its supply from external sources. Regardless of the scenario case, the study cites energy use in the transport sector to increase drastically. The proportion of private transport in passenger transport is expected to amount to 32% with 10 to 15% of the population owning cars in 2050.

Energy Policy Journal (EPJ): An Econometric Study on China's Economy, Energy, and Environment to the Year 2030

Methodology

This study considers China's energy development against an economic and environmental background. Predictions of China's energy demand and supply are generated from an integrated, econometric model (the 3E' Model) composed of a macroeconomic sub-model, an energy sub-model, and an environment sub-model. The macroeconomic sub-model provides economic indicators impacting the energy balance and uses population, fiscal policy, and overseas economic indicators. The core of the 3E's Model, the energy sub-model, is used to determine energy flow from final energy consumption to primary energy supply and energy trading position. Based on economic activity and price indicators from the macroeconomic sub-model, the energy sub-model establishes final energy demand according to sector and energy source. Primary energy consumption is acquired through aggregating energy needs from end-use and transformation sectors. The environment sub-model establishes energy-related production matrices and SO_2 and CO_2 matrices which follow the energy balance table. The 3E's model uses 631 equations: 81 in the macro sub-model and 550 for energy and environment sub-models. Data for the macro indicators were based on figures from the China Statistical Yearbook, China Fixed Asset Investment Statistical Yearbook, China Labor Statistical Yearbook, China Environment Yearbook, World Development Indicators, and other official statistics. When indicators were not accessible via consistent sources, estimations based on irregular statistical reports, research papers, etc were made. Energy data for this study is primarily pulled from IEA. Because this model heavily depends on data, the reliability of official Chinese data is problematic. GDP data from Chinese sources are frequently overestimated, while energy balance numbers are regularly underestimated. This study takes into account the tendency of underestimating energy data, but the overstatement of GDP growth is not addressed. Assuming current economic trends to continue until 2030, a Business as Usual (BAU) case for macroeconomic simulation is constructed, A BAU and five alternative scenario perspectives for China's energy balance is developed from the macroeconomic BAU case. The five alternative cases explore the following circumstances: energy savings; change to non-fossil fuels; energy savings and fuel switching, a carbon tax case, and a comprehensive scenario assuming all three conditions to take place.

Results

This study assumes China to support a rapid economic growth pace, with GDP potentially growing annually at 7%. According to the author, the technology factor will influence economic growth and its contribution will increase from 50% to 64%. In the forecast period from 1999 to 2030, total primary energy consumption in the BAU case will grow 3.6% per year, although energy intensity is predicted to decline by 2.5% every year. The share of coal in the primary energy consumption mix is expected to fall from 71% in 1999 to 53% in 2030, while natural gas consumption may rise from 3.0% to 10.5%. Oil consumption is also expected to grow, as compared to natural gas consumption rates, although at a smaller scale from 23.3% in 1999 to 28.4% in 2030. The study suggests nuclear energy to grow on a yearly basis at 13.7%. Natural gas is the main energy source which will replace coal in power generation for the next few decades. In terms of energy consumption by sector, the amount of energy used by the industry sector is expected to diminish. In 1999, industry accounted for 62% of the energy consumed, although by 2030, this percentage should fall to 41.9%. Due to better living conditions and a growing motorization process, transport energy consumption will hit 18.5%, as compared to

12.8% in 1999. When energy security is taken into consideration with the BAU scenario, a shortfall in fossil fuel supply measuring 710Mtoe will arise. When energy savings are factored into the BAU case, primary energy consumption is forecasted to be 4.8% lower and fuel imports are also expected to decline from 710 Mtoe to 661 Mtoe. By expanding its non-fossil fuel power generating capacity (fuel switching case), the country can lower fossil fuel consumption rates by 7.0% every year. When both energy security and fuel switching are incorporated into the BAU case, not only will fuel imports decline, but primary energy consumption will annually drop by 6.2%. In the case that a carbon tax is implemented on energy consumption from 2011, compared to BAU scenario results, primary energy consumption will decrease by 7.3% and fossil fuel consumption will fall by 8.0%, annually. Despite the drop in energy consumption, this scenario forecasts fuel import to rise from the 710 Mtoe in the BAU scenario to 729 Mtoe. This discrepancy occurs due to the high carbon content in coal, which compels a heavier reliance on oil and natural gas, both of which are less abundant in China. The final case in this study factors in energy security, energy switching, and a carbon tax, resulting in a 13.5% energy consumption decrease with fossil fuel consumption to fall by 19.9%. Energy import is also lower in the scenario, measured at 676 Mtoe when compared to the 710 Mtoe shortfall forecasted in the BAU case.

Coal Production					
Source	Unit	2005	2010	2015	2020
	Mt		1688-1742	1850-1926	
Japan Center for International Exchange: Rethinking Energy Security in East Asia	Median		1715	1812	
World Bank: China Issues & Options in Greenhouse Gas Emissions Control	Mt				2220
World Bank: China Issues & Options in Greenhouse Gas Emissions Control HIGH SUBSTITUTION	Mt				1915
Energy Policy: Future Implications of China's Energy-Technology Choices	Mt	1669	1823	1986	2167
Energy Policy: An Econometric Study of China's Economy, Energy, and Environment to 2030	Mtoe		836.3		1071.7
Asian Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	744.8	825.8	922.1	1053.6
International Energy Agency: World Energy Outlook 2000	Mtoe		940		1192

Coal Consumption					
Source	Unit	2005	2010	2015	2020
Energy Information Administration: International Energy Outlook 2003	Mst	1442	1811	2115	2511
REFERENCE CASE SCENARIO	Mt	1308.16	1706.41	1918.7	2646.26
Energy Information Administration: International Energy Outlook 2003	Mst	1463	1925	2334	2876
HIGH ECONOMIC GROWTH	Mt	1327.21	1746.41	1918.7	2646.26
Energy Information Administration: International Energy Outlook 2003	Mst	1346	1459	1586	1643
LOW ECONOMIC GROWTH	Mt	1221.07	1323.58	1438.80	1490.50
	Mt		1400-14500	1805-1876	
Japan Center for International Exchange: Rethinking Energy Security in East Asia	Median		1425	1835.5	
World Bank: China: Issues and Options in Greenhouse Gas Emissions Control	Mt				3100
Energy Policy: An Econometric Study of China's Economy, Energy, and Environment to 2030	Mtoe		835		1072
International Energy Agency: World Energy Outlook 2000	Mtoe		864		1107
Asia Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	699.2	765.3	859.9	989.61
Japan Bank for International Cooperation: Energy Balance Simulations to 2010 for China and Japan	Mtoe	872.6	875.9		
Japan Bank for International Cooperation: Energy Balance Simulations to 2010 for China and Japan HIGH GROWTH CASE	Mtoe	885.2	937.9		

Oil Production					
Source	Unit	2005	2010	2015	2020
Japan Center for International Cooperation: Rethinking Energy Security in East Asia	Mt		185-195	200-210	
	Median		190	205	
Energy Information Administration: International Energy Outlook 2003	Mbbl/day	3.5	3.6	3.5	3.5
REFERENCE CASE	Mt	174.251	179.23	174.251	174.251
Energy Information Administration: International Energy Outlook 2003	Mbbl/day	3.6	3.7	3.7	3.8
HIGH OIL PRICE CASE	Mt	179.23	184.208	184.208	188.668
Energy Information Administration: International Energy Outlook 2003	Mbbl/day	3.4	3.5	3.4	3.3
LOW OIL PRICE CASE	Mt	169.2724	174.251	169.2724	164.294
Energy Policy: An Econometric Study of China's Economy, Energy, and Environment to 2030	Mtoe		177.8		212.4
International Energy Agency: World Energy Agency 2000 TPES	Mtoe		371		541
Asia Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	260.3	328.3	403.6	497.2
Japan Bank For International Cooperation: Energy Balance Simulations to 2010 for China & Japan	Mtoe	182.8	201.9		
Energy Policy: Future Implications of China's Energy Technology Choices	Mtoe	167	176	183	183

Oil Consumption					
Source	Unit	2005	2010	2015	2020
Japan Center for International Cooperation: Rethinking Energy Security in East Asia	Mt		275-298	325-355	
	Median		286.5	340	
World Bank: China: Issues and Options in Greenhouse Gas Emissions Control	Mt				440
Energy Information Administration: International Energy Outlook 2003	Mt	273.823	323.609	383.3522	467.9884
Energy Policy: An Econometric Study of China's Economy, Energy, and Environment to 2030	Mtoe		316.9		487.5
International Energy Agency: World Energy Outlook 2000	Mtoe		335		488
Japan Bank for International Cooperation: Energy Balance Simulations to 2010 for China and Japan	Mtoe	196	244.6		
Japan Bank for International Cooperation: Energy Balance Simulations to 2010 for China and Japan HIGH GROWTH CASE	Mtoe	211.1	280.1		
Asia Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	260.3	328.3	403.6	497.2

Natural Gas Production					
Source	Unit	2005	2010	2015	2020
Energy Policy: Future Implications of China's Energy-Technology Choices	Gm3	56	75	92	109
	Gm3	40-45	54-73		92-110
Natural Gas in Asia: Natural Gas in China	Median	42	64		101
	Gm3		58-68	90-110	
Japan Center for International Cooperation: Rethinking Energy Security in East Asia	Median		63	100	
Asia Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	46.9	68.8	98.7	137.5
International Energy Agency: World Energy Outlook 2000	Mtoe		56		111
	Mtoe		76.1		123.9

Natural Gas Consumption					
Source	Unit	2005	2010	2015	2020
Natural Gas in Asia: Natural Gas in China SLOW GROWTH	Gm3	41	70		120
Natural Gas in Asia: Natural Gas in China ACCELERATION AND LIBERALIZATION	Gm3	48	105		200
Energy Information Administration: International Energy Outlook 2003 REFERENCE CASE	Gm3	39.644	65.129	107.604	127.423
Energy Information Administration: International Energy Outlook 2003 LOW ECONOMIC GROWTH	Gm3	36.812	48.139	59.465	113.267
Energy Information Administration: International Energy Outlook 2003 HIGH ECONOMIC GROWTH	Gm3	39.643	73.624	121.762	152.911
Japan Center for International Cooperation: Rethinking Energy Security in East Asia	Bm3 Median		75-90 82.5	150-200 175	
World Bank: China: Issues and Options in Greenhouse Gas Emissions Control	Gm3				115
Asia Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 200	Mtoe	46.9	68.8	98.7	137.5
International Energy Agency: World Energy Outlook 2000	Mtoe		49		97
	Mtoe		79.7		163.5

Nuclear Production					
Source	Unit	2005	2010	2015	2020
Asian Pacific Energy Research Center: APEC Energy Demand and Supply Outlook 2002	Mtoe	16.9	24	31	38.8
International Energy Agency: World Energy Outlook 2000	Mtoe		52		57
	Mtce				72
World Bank: China: Issues and Options in Greenhouse Gas Emissions Control	Mtoe				50.4
World Bank: China: Issues and Options in Greenhouse Gas Emissions Control	Mtce				198
HIGH SUBSTITUTION	Mtoe				138.6

Nuclear Consumption					
Source	Unit	2005	2010	2015	2020
Energy Information Administration: International Energy Outlook 2003 REFERENCE CASE	GW	57,000	66,000	129,000	131,000
Energy Information Administration: International Energy Outlook 2003 LOW ECONOMIC GROWTH	GW	57,000	66,000	125,000	122,000
Energy Information Administration: International Energy Outlook 2003 HIGH ECONOMIC GROWTH	GW	57,000	67,000	137,000	145,000
	GW		41,230		82,460

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